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RELATIONSHIP AIRLOAD
TO WIND-SHOCK ABSORBER
ACROSS FACE IN VERTICAL PLANE

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20. ABSTRACT (cont'd):

was provided for many drops. Variation of platform acceleration with load mass and impact velocity was determined for two choke sizes. The airbags exhibited premature skirt crush which would adversely affect ground slide. Average platform acceleration levels ranged from 3.6 to 8.7 G, but peak accelerations were generally twice as high, ranging from 6.8 to 17.7 G.

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PREFACE

The present system of airdropping military vehicles and equipment incorporates paper honeycomb to mitigate impact shock. Paper honeycomb is an effective energy absorber but has several drawbacks which make it difficult to use. The balloon-skirt airbag, or atterroglisseur, developed in France, has the potential to replace paper honeycomb. In the 1970's our attempts to obtain detailed airbag engineering and test data met with little success. In order to determine the performance and limitations of the balloon-skirt airbag, a set of eight were procured from the developer, Bertin & Cie, France, for in-house evaluation.

The author wishes to acknowledge the test work done by the Experimental Analysis and Design Division of AMEL. The skilled efforts of John Buckley, Mike Hope, John Lanza, and John Lupien, in providing the test data that is the foundation of this report, are appreciated.

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BALLOON-SKIRT AIRBAGS AS AIRDROP SHOCK ABSORBERS: PERFORMANCE IN VERTICAL DROPS

INTRODUCTION

In July 1979, US Army Natick R&D Laboratories awarded Contract DAAK60-79-C-0064 to Société Bertin & Cie, Plaisir, France, to supply an eight-airbag balloon-skirt impact shock attenuation system. Used with platform-mounted vehicles and equipment parachuted from aircraft, these airbags are designed to dissipate the impact energy of the approximate 8 m/s vertical impact velocity. The Bertin system was designed to limit vertical accelerations to approximately 7 G and eliminate platform overturn under the following airdrop conditions:

- maximum airdropped mass of 2000 kg
- vertical velocity up to 8 m/s
- horizontal velocity up to 15 m/s

Throughout this report the notation G will stand for "times the acceleration of gravity at sea level" or times 9.8 m/s². The airbag features a balloon and skirt separated by a polyethylene intermediate platform as shown in Figure 1. A removable choke is attached over a hole in the intermediate platform; the choke restricts airflow out of the balloon. The airbag material is polyester (100 g/km) coated with neoprene on the outside and hypalon on the inside, with a mass of 1000 g/m² and thickness of 0.84 mm.

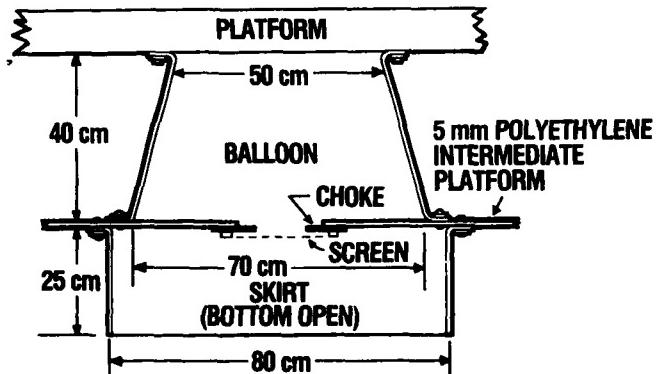


Figure 1. Cross-Sectional View
of Balloon-Skirt Airbag

The theory of operation involves a two stage crush, with the balloon crushing first (due to the smaller diameter) in approximately 0.1 s, followed by the skirts crushing over approximately a 1 s interval. Proper sizing of the choke orifice maintains optimum balloon

pressure during crush and results in reducing the load velocity to near zero at the end of balloon crush. The skirts are fed with balloon air faster than air leaks out between the skirt and the ground, so that during balloon crush the skirts remain full of air and act as air cushions. The friction with the ground slowly increases as the air is exhausted from the skirts, and if there is a horizontal velocity present, a gradual sliding stop is achieved.

Several features and capabilities, nonexistent with the present airdrop system, would be present in a balloon-skirt airbag system:

- (a) vehicle roll-on/roll-off capability
- (b) simplified rigging and derigging
- (c) overturns are eliminated
- (d) capability of high wind airdrops
- (e) reusable
- (f) low CG in aircraft — airbags are folded
- (g) unaffected by moisture or rain (unless it freezes)

These features and capabilities, if incorporated into a practical platform, would vastly improve and simplify the airdrop of equipment, vehicles and cargo. Therefore, a set of eight airbags was ordered for evaluation and test at NLABS. Test work concentrated on determining the effect of variations in load mass, impact velocity, and choke diameter on the platform acceleration. To do this, two of these three variables were held constant while the third was varied, and platform position and acceleration was recorded.

LITERATURE

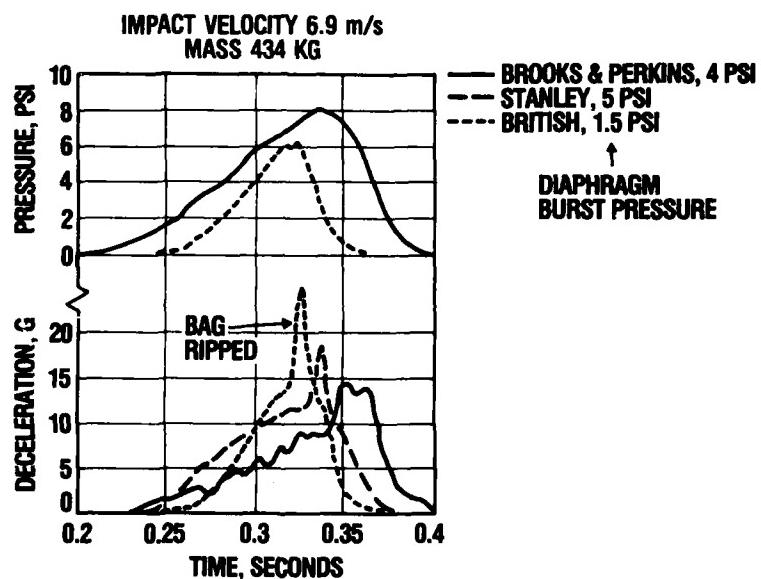
Airbags have been around for many years and have been considered for use as airdrop platform cushioning devices for about 30 years.

In December 1953, three types of barrel-shaped airbags were tested by Wright Patterson AFB.¹ All three airbags had approximate dimensions: 100 cm high, center diameter 90 cm, and top and bottom diameter 60 cm. These airbags all featured a check valve on the bottom, allowing inflation, and a top or side mounted diaphragm designed to burst at a predetermined pressure.

¹ Madaffer, M.C. Evaluation of Three Types of Airbag Decelerators by Drop Tests, Wright Patterson AFB, Ohio, Technical Note WCLE-54-11, December 1953 (AD 857025).

The Brooks and Perkins airbag was made of vulcanized, rubberized nylon and used steel spring hoops to maintain its barrel-shaped form. It featured a top-mounted, 15 cm diameter orifice which could be covered with diaphragms designed to burst at 2, 4 and 5.7 psi (14, 28 and 39 kPa). The Stanley airbag was made of cold cemented rubberized nylon and used cable hoops to maintain its shape. It featured five 7.6 cm orifices spaced around the center circumference, with diaphragms designed to burst at 5 psi (34 kPa). The British airbag was made of rubberized cotton and used cable hoops to maintain its shape. It featured a top 15 cm diameter orifice with a diaphragm designed to burst at 1.5 psi (10 kPa).

Test drops were made with one of each airbag under a test platform using a 2.4 m drop height, and load masses of 363, 454, 545, and 682 kg. An example of pressure and deceleration data for a 434 kg load is shown in Figure 2. Airbags reached pressures of 6 to 8 psi (41 to 55 kPa), and acted over a period of approximately 0.15 seconds. Platform decelerations peaked at 14, 18, and 25 G for the Brooks & Perkins, Stanley, and British airbags respectively.



**Figure 2. Typical Data for Three Airbags
(from Reference 1)**

Conclusions reached were (1) spring hoops are preferred over cable hoops; (2) rubberized nylon is superior to rubberized cotton; (3) the vulcanized airbag is more durable than the cold-cemented airbag; and, (4) the side mounted diaphragms on the Stanley airbag may have been constricted during bag crush, probably causing load bounce and topple.

In 1959, three types of airbags were tested by University of Texas, a United Kingdom (UK) cylindrical airbag, a UK barrel-shaped airbag, and a Goodyear airbag.² The UK cylindrical

²Turnbow, J. and W. Ogletree. The Energy-Dissipating Characteristics of Airbags, US Army QMR&E Command Contract DA 19-129-QM-1383 to University of Texas Structural Mechanics Research Laboratory, Austin, Texas, August 1595 (AD 228787).

bag was 94 cm in diameter and 137 cm long. The bottom of the bag had a 30 cm diameter filling sleeve which closed on ground impact, while at the top were four 8 cm diameter orifices covered with rupture diaphragms. The UK barrel-shaped bag, also made of rubberized fabric, was 111 cm long; no diameter data was given. These bags had a 14 cm top orifice with rupture diaphragm, and a 29 cm filling orifice in the base. The Goodyear airbags were cylindrical, of heavier rubberized fabric, 90 cm diameter and 130 cm long. The filling ports consisted of five 6 cm diameter orifices covered by a one-way flap valve. The 11 cm top outlet orifice included 4 gum rubber gussets, permitting expansion of the orifice with increasing pressure.

A test program concentrated on single airbag test drops, with a range of loads from 300 to 820 kg, and with impact velocities from 5.5 to 10.7 m/s. Typical data for the Goodyear airbag is included in Figure 3. Conclusions reached were (1) all three airbags are capable of dissipating up to 18,000 ft-lb (24,400 J) of energy; and (2) all airbags experienced a slow pressure rise causing the initial part of the stroke to be ineffective; (3) a single airbag is extremely unstable; and (4) horizontal wind gusts deflect the bag and would present a platform overturn problem.

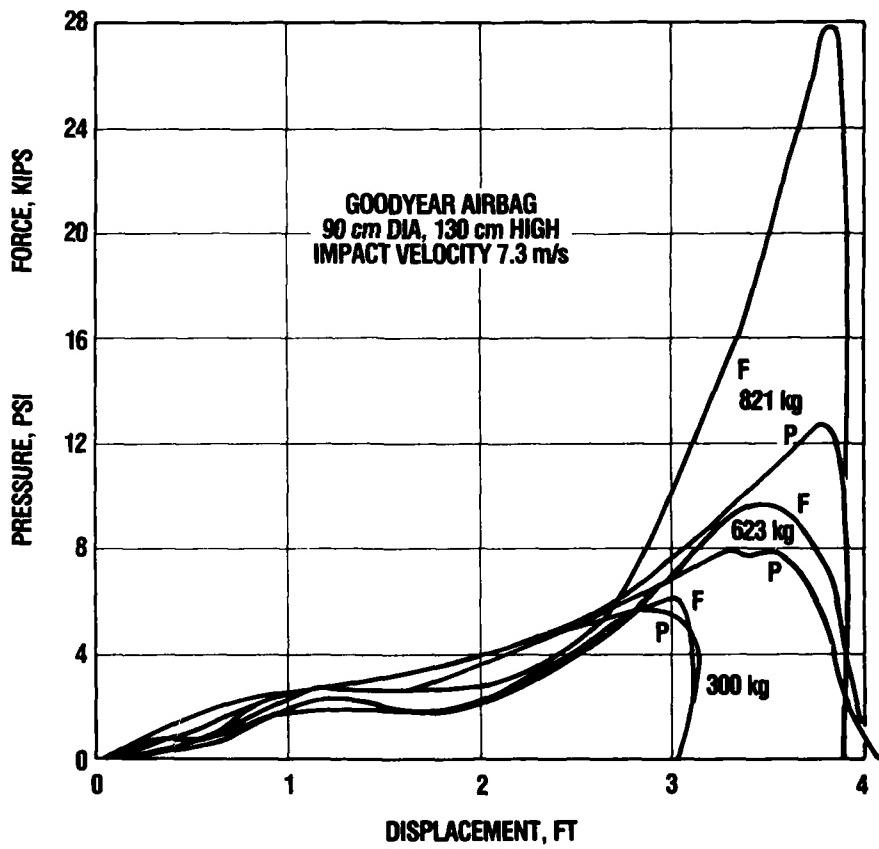


Figure 3. Pressure and Force vs. Displacement,
Goodyear Airbag (from Reference 2)

In 1960 a study and analysis of barrel-shaped airbags as well as airbag decelerator requirements with an attempt to improve efficiency, resulted in a new cylindrically-shaped airbag.³ The cylindrical airbag is 90 cm in diameter and 114 cm high, with a five hole one-way filling port in the bottom and a variable diameter orifice and blow-out diaphragm in the top. The airbag is made of a rubberized fabric, as lightweight as possible to assure cold weather flexibility, and has flexible metal cable hoops attached to the bag to reinforce the fabric and hold the cylindrical shape. A total of 35 drop tests were carried out, 21 of which were four-bag tests. Single airbag tests data showed peak pressure for a 630 kg load to be 7.3 to 17.6 psi (50 to 121 kPa) for impact velocities ranging from 6.4 to 9.4 m/s. Airbag induced vertical

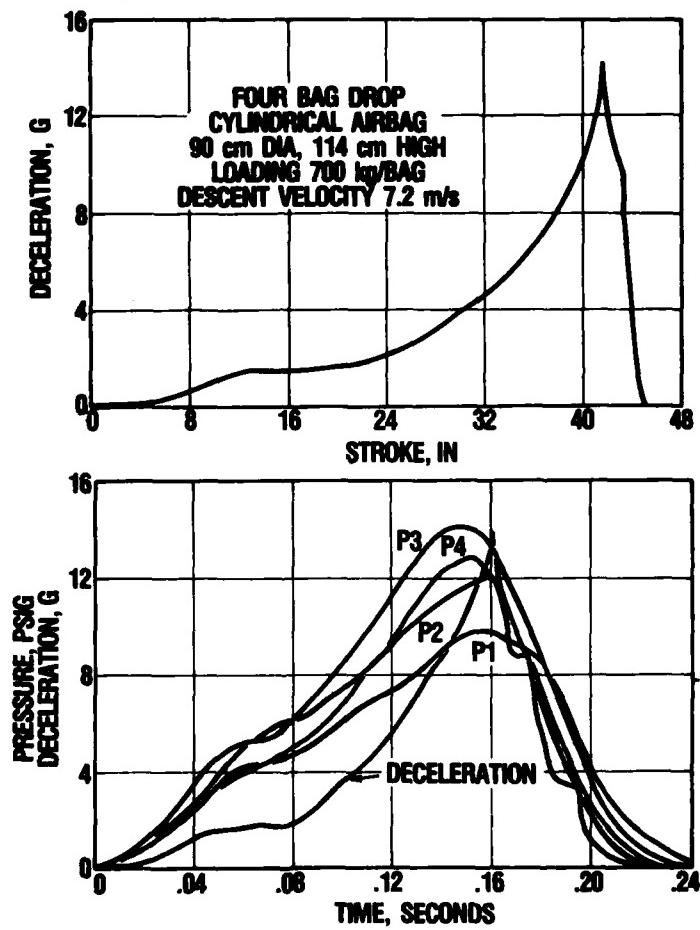


Figure 4. Four Bag Test Data for Cylindrical Airbag (from Reference 3)

³ Tomcsak, S. Decelerator Bag Study, WADC TR 59-775, Wright Patterson AFB, Ohio, Contract AF 33(600)-30825 to Goodyear Tire and Rubber Co., Akron, Ohio, June 1960 (AD 243159).

deceleration was 4.1 to 12.8 G, while platform impact deceleration was 7.5 to 25.6 G vertical and up to 13 G horizontal. Although drops were vertical, the airbags would often slant under the platform, causing the airbags to buckle and the platform to hit obliquely, resulting in higher deceleration values due to platform impact. Four-airbag data was similar, except horizontal impact velocities due to uneven platform impact were lower, on the order of 1 to 5 G. Data for a typical four-bag test is shown in Figure 4. A parachute drop test was conducted with a 7.3 m platform housing 12 airbags. For this drop, impact velocity was 8.4 m/s while horizontal velocity due to winds was 2.5 to 5 m/s. For this 12 airbag drop airbag pressures were lower than expected (8 psi), as was the platform acceleration; validity of data was doubted. It was concluded that the cylindrical airbag with the variable diameter orifice was more efficient than previous airbags.

In an English study in 1963, a theory of compression of a cylindrical airbag was developed and equations were solved by numerical integration.⁴ Dimensionless parameters were developed for bag height, bag loading, and orifice size, and a series of charts were drawn up so the performance of a given airbag could be determined. It was found that airbags were most suitable at a loading of 150–200 lb/ft² (7.2 to 9.6 kPa), and very high or low loadings were inefficient. It was stated that it is unreasonable to expect an airbag to reduce impact velocity by more than 70%, so a descent velocity of 7.6 m/s should be reduced to about 2.3 m/s by the airbags. In this case, however, kinetic energy is reduced by 90%. Using an impact velocity of 7.6 m/s, the charts indicate a good airbag would be 80 cm high, 60 cm in diameter, and given the proper orifice, could retard any load mass between 110 and 410 kg from 7.6 to 2.4 m/s with a peak acceleration of about 8 G. The ground impact velocity of 2.4 m/s (equivalent to a 29 cm free-fall) would impart a substantial shock to the platform on hard terrain, greater than the 8 G airbag deceleration, and it was indicated the platform must be robust to withstand this. The charts indicate that \pm 20% variation of the load on a given airbag change the peak acceleration by less than \pm 5%, while changes in impact velocity of \pm 20% change the peak acceleration by +57% and -40%. Although no drop tests were made, the theory was found to be in reasonably good agreement with some earlier test data. It was noted that for the theory to be valid in wind drift conditions, wind velocity must be no more than 1.8 m/s.

A final report of Bertin's work on airbag damping devices covered research and tests over the time period 1963–1968.⁵ The work was done under contract to the French Army (Direction Technique Des Armements Terrestres, Toulouse) to develop a device to permit airdrops in strong winds with no platform overturn and to dampen the impact so that equipment would be subjected to decelerations no more than those of their standard airdrop system. The report made reference to experiments conducted by Bertin in 1961 in which only flexible skirts were used to attenuate a platform's vertical descent. The poor performance and platform

⁴Browning, A.C. A Theoretical Approach to Airbag Shock Absorber Design. Technical Note ME369, Royal Aircraft Establishment, Farnborough, England, February 1963 (AD 421946).

⁵Lebargy, P. Damping of Parachute Loads, Final Report, Technical Memorandum 681f29, Bertin & Co., Plaisir, France, November 1968.

overtake tendency of the skirts — only approach gave rise to a balloon-skirt airbag, which greatly reduced the ground friction and rebound. Upon contract to the French Army, Bertin then investigated various sizes and shapes of balloon-skirt airbags. A theoretical study of balloon-skirt airbag operation was first carried out and a computer program was written. The program calculated the choke diameter which, for a given airbag size and loading, resulted in zero platform velocity at the end of balloon crush. Early tests used compressed air to pressurize the airbags just prior to impact; attempts to simplify the system, however, resulted in satisfactory operation without compressed air. Drop tests were first made in the laboratory (292 drops), then from a mobile crane (238) then a helicopter (6), and finally from a fixed-wing aircraft, the Transall C-160 (22). During the research program, it was found that to avoid skirt buckling the skirt diameter-height ratio must be approximately 4. Also, to keep ground shear action from being excessive, the balloon height must be shorter than the average balloon diameter. The conclusions reached were (a) tests in wind velocities up to 15 m/s confirmed the elimination of platform overturn, (b) the balloon-skirt assembly operated within standards for vertical velocities between 6 and 10 m/s and (c) platform accelerations were less than 10 G in normal conditions of use, and did not exceed 18 G at an impact velocity of 12 m/s.

PLATFORM DESIGN AND INSTRUMENTATION

Bertin Document No. 79-58, the instruction manual delivered with the airbags, recommended a platform size of 3.5 by 1.8 m, with a side shoe extending out an additional 0.2 m on all sides.⁶ The overall platform size would then be 3.9 by 2.2 m.

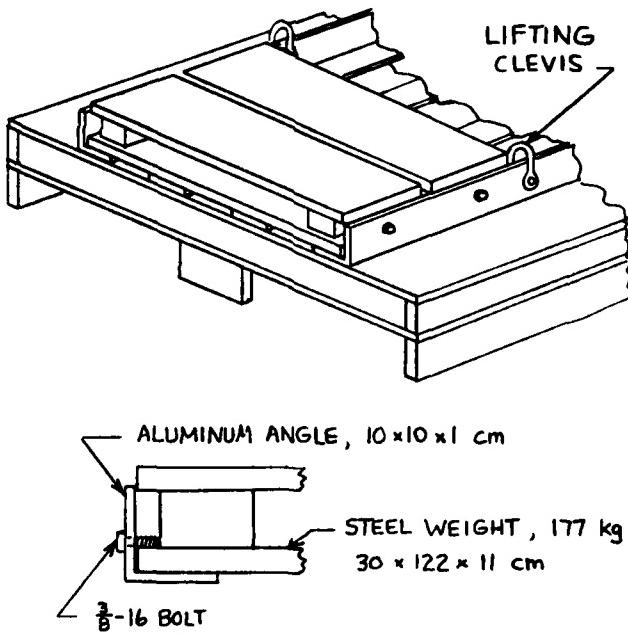


Figure 5. Anchoring of Steel Weights

⁶ Croix-Marie, F. and P. Lebargy. Airdrop Landing Platform Damper No. 1, Document 79-58, Bertin & Cie, 78370 Plaisir, France, 1979.

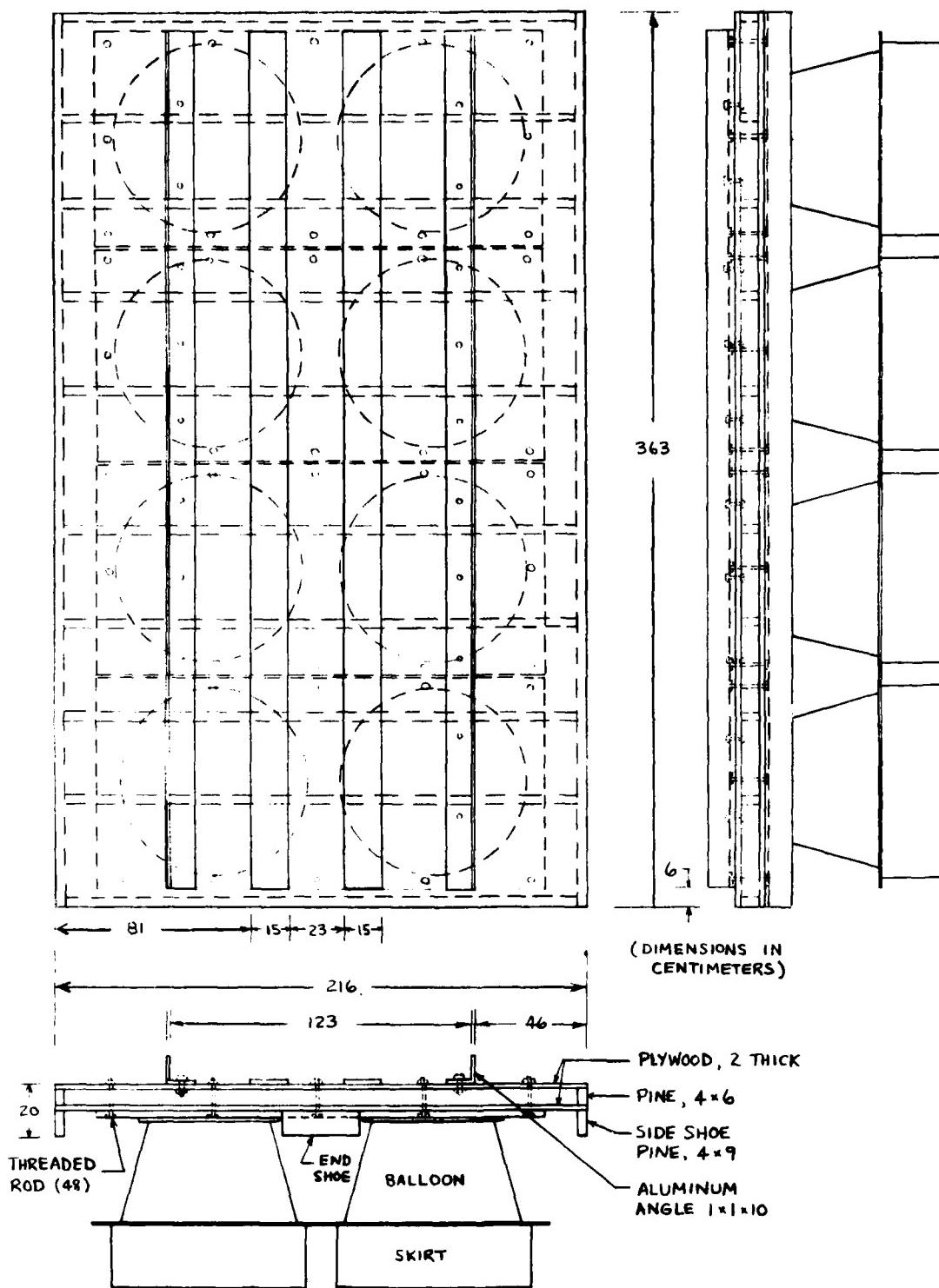


Figure 6. Platform Design

For this test program, a wood test platform designed to holdup to 11 steel weights was fabricated. This platform was built solely as a test device to obtain data on the airbag performance in vertical drops. Figure 6 shows the platform design. The two 10 x 10 x 1 cm aluminum angles running the length of the platform provided a mounting and anchoring surface for the steel weights. The method of anchoring the weights is shown in Figure 5.

The platform mass was 436 kg, and each steel weight had a mass of 177 kg. Table 1 lists the total mass for the nine test configurations.

Table 1

Total Platform Mass

| Number of Weights | Total Mass (kg) | Total Mass (lb weight) |
|-------------------|-----------------|------------------------|
| 3 | 968 | 2130 |
| 4 | 1145 | 2520 |
| 5 | 1323 | 2910 |
| 6 | 1500 | 3300 |
| 7 | 1677 | 3690 |
| 8 | 1855 | 4080 |
| 9 | 2032 | 4470 |
| 10 | 2209 | 4860 |
| 11 | 2386 | 5250 |

Figure 7 shows the platform set up with 7 weights and indicates locations of all transducers. Three accelerometers were cemented to the top of the steel weights, a location where platform vibration least affected acceleration values. Bell & Howell accelerometers were used, with ranges ± 15 G, ± 25 G and ± 100 G. Pressure transducers used were Data Instrument Model AB-25, strain gage type, with range 0 to 25 psi (0 to 172 kPa) gage; these were mounted with steel guard members to protect the pressure-sensing face from impact. The position transducer, Celesco model PT-101-100A, had a 2.5 m active length. Since many of the drops were from 3.5 m height, the position transducer had to be used with some slack, resulting in position data on only the last half of the platform descent. This was no problem. Ground contact switches were Microswitch model BZ-2RW-Z2. All of the above transducer outputs were recorded on a Honeywell model 1858 17-channel Visicorder. The Visicorder features a multi-grid cathode ray tube with fiber optics to achieve a very high frequency response; a chart speed of 2.5 m/s gave a clear indication of all pressure and acceleration variations. A Wollensak Fastax high speed 16 mm motion picture camera was used at various speeds, ranging from 450 to 1800 frames per second, to record the impact.

Figure 8 shows two views of the airbag platform suspended above the ground. The layer of paper honeycomb on top protects the center accelerometer from impact from the release mechanism. Figure 9 shows a view of the platform in mid-drop and a view showing the high speed camera. These photographs show the quick release attached to the crane hook, and the forklift used to mount the position transducer.

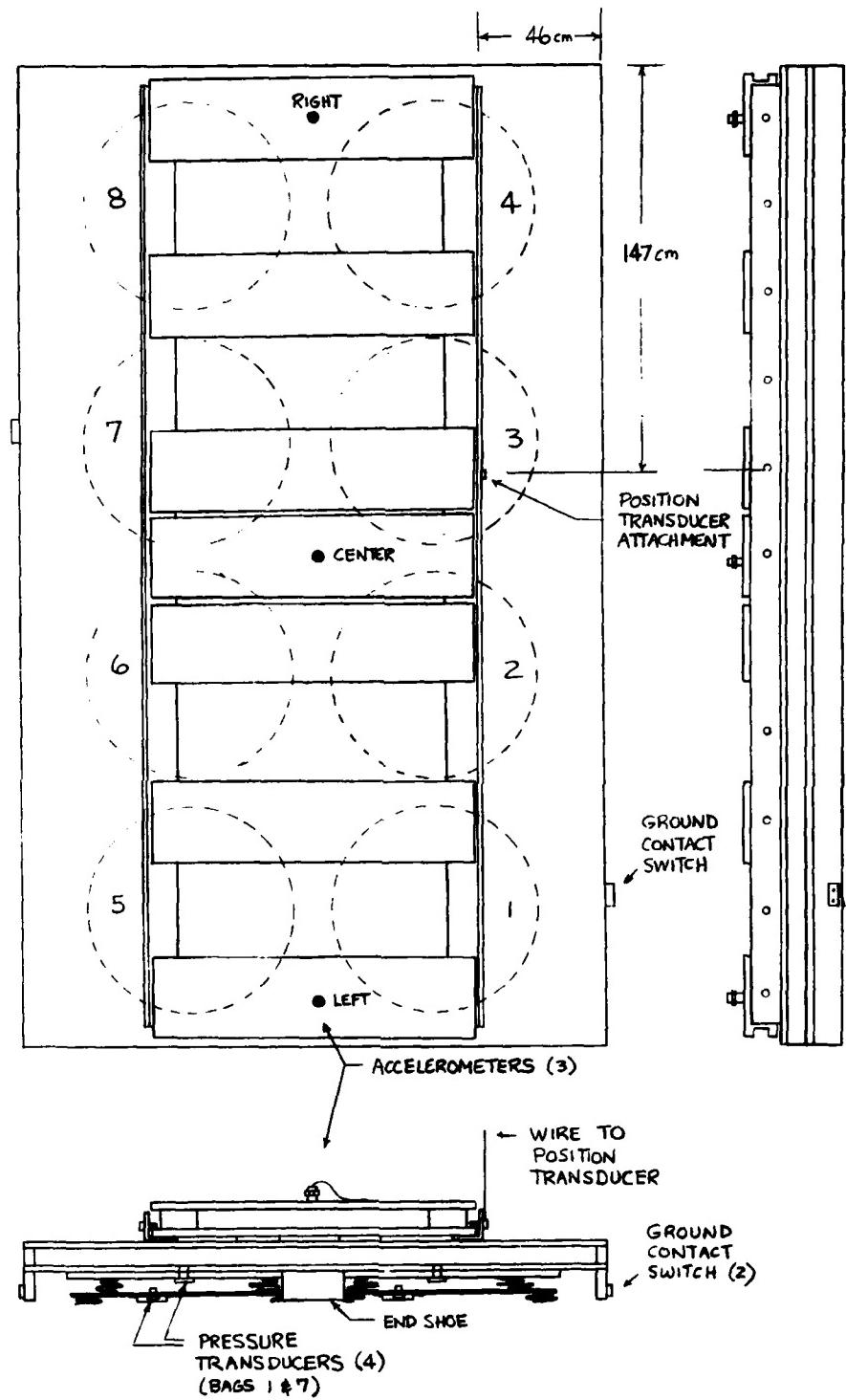


Figure 7. Platform Instrumentation

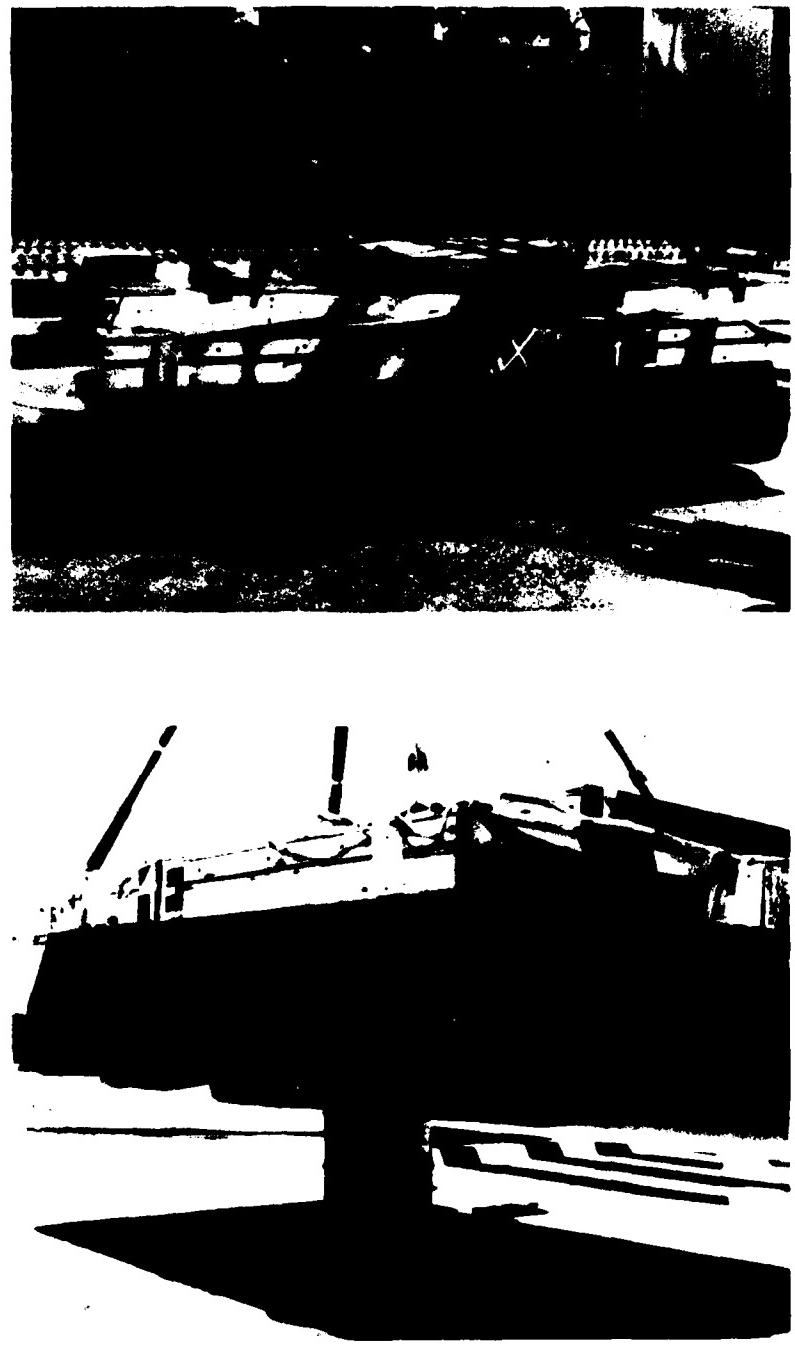


Figure 8. Airbag Platform: Two Overall Views

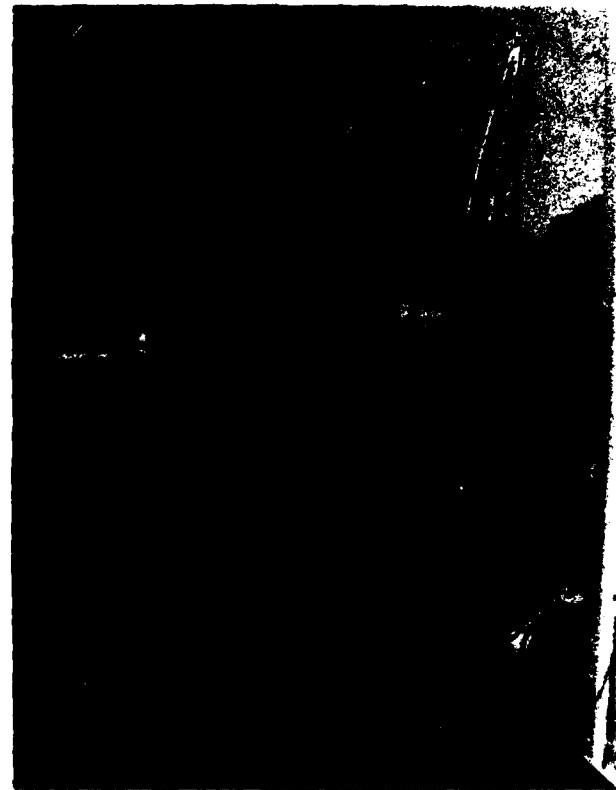


Figure 9. Airbag Platform: Mid-Drop and Camera View

TEST PLAN AND PROCEDURE

Data supplied with the shipment of the airbags (Ref 6) included two graphs, redrawn here as Figures 10 and 11. In Figure 10, the effect of impact velocity on platform acceleration is shown; an increase of impact velocity of 5 to 8 m/s is accompanied with an increase in platform acceleration of 50 to 60 percent. Accelerations given in these graphs are referred to in reference 6 as "calculated acceleration of the center of gravity of the load," which we interpreted to mean average acceleration. Figure 11 indicates over what mass ranges the chokes should be used to achieve approximately a 7 G acceleration over a velocity range of 5 to 8 m/s.

The purpose of this test was to evaluate the performance of the airbag and to verify its effectiveness of maintaining approximately a 7 G impact acceleration over both a range of load mass and a range of impact velocity.

The original test plan is included as Table 2. A moderate weight (1323 kg) was planned to debug the data recording system, followed by a systematic investigation of load and velocity effects on platform deceleration, with 120 and 140 mm chokes.

Table 2

Test Plan for Balloon-Skirt Airbag Platform

| Drop No. | No. of Steel Weights | Platform Mass (kg) | Impact Velocity (m/s) | Choke Dia (mm) | Comments |
|----------|----------------------|--------------------|-----------------------|----------------|--|
| 1 | 5 | 1323 | 8 | 120 | |
| 2 | 5 | 1323 | 8 | 120 | |
| 3 | 6 | 1500 | 8 | 120 | Variations of Accel. with Load Mass |
| 4 | 7 | 1677 | 8 | 120 | |
| 5 | 8 | 1855 | 8 | 120 | |
| 6 | 9 | 2032 | 6 | 120 | |
| 7 | 9 | 2032 | 7 | 120 | Variations of Accel. with Velocity |
| 8 | 9 | 2032 | 8 | 120 | |
| 9 | 9 | 2032 | 9 | 120 | |
| 10 | 9 | 2032 | 10 | 120 | |
| 11 | 10 | 2209 | 8 | 120 | Overload |
| 12 | 11 | 2386 | 8 | 120 | |
| 13 | 7 | 1677 | 8 | 140 | Low-Range Variation of Accel. with Load Mass |
| 14 | 5 | 1323 | 8 | 140 | |
| 15 | 3 | 968 | 8 | 140 | |
| 16 | 6 | 1500 | 6 | 140 | Low-Range Variation of Accel. with Velocity |
| 17 | 6 | 1500 | 8 | 140 | |
| 18 | 6 | 1500 | 10 | 140 | |

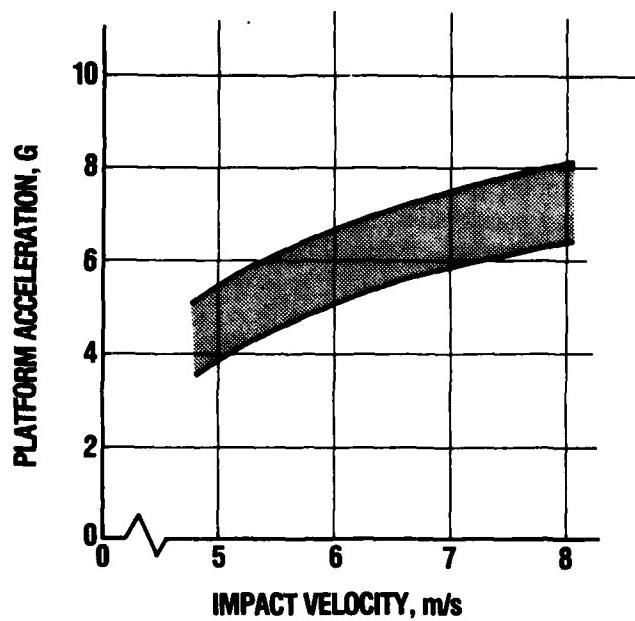


Figure 10. Range of Platform Acceleration for Various Impact Velocities (from Ref. 6)

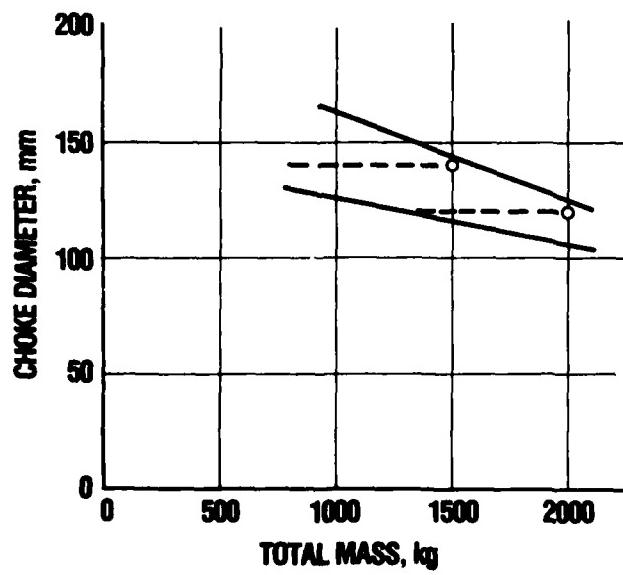


Figure 11. Mass Range for Two Choke Diameters, for Acceleration ≈ 7 G, Impact Velocity 5 to 8 m/s (from Ref. 6)

Test drops were conducted outdoors, adjacent to the Roller Test Facility, at NLABS. The impact surface was asphalt.

The procedure followed in a typical drop was as follows:

- a. Clear impact area of dirt, sand, or standing water.
- b. Mount and secure the proper number of weights in a symmetrical manner on the platform.
- c. Check for proper operation of all transducers.
- d. Cement the accelerometers to the appropriate weights.
- e. Attach suspension sling clevis to crane hook, without using release mechanism. Raise platform approximately 0.5 m above the ground, check to see if each corner is approximately the same distance (within an inch) above the ground. If not, lower platform, adjust slings, and repeat procedure.
- f. Attach release mechanism between suspension clevis and crane hook.
- g. With platform on ground, electrically zero position transducer, align camera, write drop number and date on platform.
- h. Raise platform about 2 m off ground, attach height determining cable to intermediate platform, make sure all airbags are fully extended, and raise platform to full height.
- i. Remove height cable, align platform directly above impact point, and steady platform.
- j. Release platform and immediately start data recorder and motion picture camera as platform begins to fall.
- k. After the drop, remove release mechanism, raise platform approximately 2 m, inspect airbags and platform for damage.

TEST RESULTS AND DISCUSSION

Test Chronology and Data Summary

A total of 43 platform drops were conducted over the period 26 Jun 80 to 17 Jul 81. Table 3 summarizes the data recorded for each drop. The drop numbering system was based on the test plan (see Table 2), with repeat drops denoted by adding letters, increasing alphabetically, after the drop number.

The first five drops were run to gain experience in the range of data variation, and to properly space data on the somewhat narrow (200 mm) Visicorder chart paper. Accelerometers

Table 3
Data Summary

| Drop No. | Date | Seq. No. | Steel Wts. | Calc. | | Peak Airbag Pressures (psi) | | | | Accelerometer Peak Values (G) | | | Mass. Imp. Speed (f/s) | | | Comments | |
|------------------------------------|----------|----------|------------|-------|----------------|-----------------------------|-----------------|-----------|-----------|-------------------------------|-----------|----|------------------------|------|-----------|-----------------|------------------------------------|
| | | | | No. | Load Mass (kg) | Imp. Vel (m/s) | Choke Dia. (mm) | Bag 1 Bal | Bag 1 Skt | Bag 7 Bal | Bag 7 Skt | L | C | R | Vel (m/s) | Peak Accel. (G) | |
| 1 | 6/26/80 | 1 | 5 | 1304 | 8 | 120 | 6.7 | 5.9 | 2.7 | 2.2 | D | | | | | | |
| 1A | 6/26/80 | 2 | 5 | 1304 | 8 | 120 | 2.8 | 1.3 | 5.7 | 3.5 | A | | | | | | |
| 1B | 6/26/80 | 3 | 5 | 1304 | 8 | 120 | 4.9 | 3.0 | 4.0 | 2.2 | T | | | | | | |
| 1C | 6/26/80 | 4 | 5 | 1304 | 8 | 120 | 3.8 | 3.3 | 2.5 | 2.0 | U | | | | | | |
| 1D | 6/26/80 | 5 | 5 | 1304 | 8 | 120 | - NO DATA - | | | | | N | | | | | |
| 1E | 6/27/80 | 6 | 5 | 1304 | 8 | 120 | 4.2 | 3.0 | 2.8 | 1.2 | R | | | | | | |
| 1F | 6/27/80 | 7 | 5 | 1304 | 8 | 120 | - NO DATA - | | | | | A | | | | | |
| 1G | 7/01/80 | 8 | 5 | 1304 | 8 | 120 | 4.0 | 3.2 | 3.2 | 1.8 | E | | | | | | |
| 1H | 7/01/80 | 9 | 5 | 1304 | 8 | 120 | 6.0 | 4.0 | 2.5 | 1.2 | | | | | | | |
| 1I | 8/26/80 | 10 | 5 | 1304 | 8 | 120 | 4.2 | Fail | 6.5 | 4.5 | | | | | | | Data filters added |
| 1J | 8/29/80 | 11 | 5 | 1304 | 8 | 120 | 4.0 | - | 4.0 | 2.0 | | | | | | | [Foam Under Weights] |
| 1K | 8/29/80 | 12 | 5 | 1304 | 8 | 120 | 5.0 | - | 5.0 | 3.0 | | | | | | | |
| 2 | 9/02/80 | 13 | 5 | 1304 | 7.7 | 120 | 3.7 | - | 5.5 | 4.0 | | | 27 | | | | |
| 3 | 9/03/80 | 14 | 6 | 1482 | 8 | 120 | 4.0 | - | 6.2 | - | 18 | 22 | 26 | 1800 | 8.2 | 15.0 | Accel on top of L, C and R Weights |
| 4 | 9/04/80 | 15 | 7 | 1659 | 8 | 120 | 6.9 | - | 8.5 | 3.2 | 32 | 25 | 23 | 1800 | 9.1 | 20.4 | |
| 5 | 9/04/80 | 16 | 8 | 1836 | 8 | 120 | 9.0 | - | 9.7 | Fail | 32 | 25 | 28 | 1800 | 8.7 | 23.8 | [Poor Film Quality] |
| 6 | 9/04/80 | 17 | 9 | 2014 | 8 | 120 | 9.0 | - | 11.0 | - | 30 | 26 | 32 | 1800 | 8.8 | 20.4 | |
| 12 | 9/04/80 | 18 | 11 | 2368 | 8 | 120 | 12.5 | - | 11.8 | - | 28 | 30 | 33 | 1800 | 9.4 | 22.0 | |
| 11 | 9/22/80 | 19 | 10 | 2190 | 8 | 120 | 13.5 | - | 10.5 | - | Fail | 35 | O.C. | 400 | - | - | Rip-Skirt 4 |
| 11A | 9/22/80 | 20 | 10 | 2190 | 8 | 120 | 18.0 | - | 11.0 | - | - | 37 | O.C. | 690 | 8.5 | 20.4 | Rip-Sk5, Ba14 |
| - PLATFORM MODIFIED - | | | | | | | | | | | | | | | | | |
| 2A | 12/22/80 | 21 | 5 | 1323 | 7.7 | 120 | 8.6 | 4.5 | 9.0 | 6.3 | 13 | 19 | 20 | 1000 | Film | 25°F | |
| 2B | 12/22/80 | 22 | 5 | 1323 | 7.7 | 120 | 12.8 | 8.3 | 10.0 | 7.3 | 12 | 14 | 20 | 1000 | Dark | Rip-Skirt 1 | |
| 2C | 1/21/81 | 23 | 5 | 1323 | 7.7 | 120 | 11.2 | 7.1 | 7.8 | 5.3 | 14 | 14 | 17 | 1050 | 7.0 | 11.0 | 34°F |
| 3A | 2/09/81 | 24 | 6 | 1500 | 7.7 | 120 | 13.4 | 8.5 | 8.7 | 6.0 | 16 | 13 | 14 | 1060 | 7.0 | 11.6 | 32°F |
| 3B | 2/10/81 | 25 | 6 | 1500 | 7.7 | 120 | 12.2 | 7.5 | 8.7 | 5.3 | 18 | - | 16 | 1050 | 7.1 | 11.0 | 37°F |
| 4A | 2/10/81 | 26 | 7 | 1677 | 7.7 | 120 | 12.0 | 7.0 | 8.5 | 5.5 | 15 | 19 | 22 | 1090 | 7.4 | 13.4 | 37°F |
| 4B | 4/09/81 | 27 | 7 | 1677 | 7.7 | 120 | 19.0 | 12.5 | 11.5 | 9.0 | 29 | 26 | - | 700 | 7.4 | 13.9 | 70°F Ground switch added |
| 4C | 4/09/81 | 28 | 7 | 1677 | 7.7 | 120 | 17.5 | 11.2 | 10.7 | 9.0 | 25 | 23 | - | 700 | 7.4 | 14.7 | Skirts 1 & 2 Exch |
| 7 | 4/30/81 | 29 | 7 | 1677 | 7.7 | 120 | 13.2 | 9.7 | 11.8 | 8.0 | 19 | 15 | - | 500 | 7.4 | 14.3 | Skirt 5 Rips |
| 8 | 5/20/81 | 30 | 7 | 1677 | 6.7 | 120 | 14.0 | 11.0 | 6.7 | 4.5 | 10 | 10 | - | 900 | 6.4 | 10.2 | Poss XDCR Added |
| 9 | 6/02/81 | 31 | 7 | 1677 | 5.5 | 120 | 6.5 | 4.5 | 6.7 | 4.0 | 8 | 9 | - | 450 | 5.4 | 6.8 | Skirts 5 & 6 Exch |
| - 140 MM CHOKES INSTALLED - | | | | | | | | | | | | | | | | | |
| 13 | 6/11/81 | 32 | 6 | 1500 | 5.5 | 140 | 7.2 | 4.2 | 4.8 | 3.6 | 20 | 10 | - | 450 | 5.4 | 7.3 | 75°F |
| 14 | 6/11/81 | 33 | 6 | 1500 | 6.7 | 140 | 7.4 | 5.4 | Fail | 5.6 | 19 | 13 | - | 450 | 6.4 | 10.2 | |
| 15 | 6/11/81 | 34 | 6 | 1500 | 7.7 | 140 | 13.0 | 9.4 | - | 6.8 | 22 | 17 | - | 450 | 7.4 | 13.6 | |
| 16 | 6/11/81 | 35 | 5 | 1323 | 7.7 | 140 | 13.5 | 11.5 | - | 5.0 | 26 | 24 | - | 450 | 7.4 | 11.6 | |
| 17 | 6/11/81 | 36 | 4 | 1145 | 7.7 | 140 | 9.0 | 7.0 | - | 6.2 | 19 | 13 | - | 450 | 7.4 | 9.0 | |
| 18 | 6/11/81 | 37 | 3 | 968 | 7.7 | 140 | 6.8 | 4.8 | - | 5.5 | 13 | 14 | - | 450 | 7.4 | 8.8 | |
| - 120 MM CHOKES INSTALLED - | | | | | | | | | | | | | | | | | |
| 2D | 6/30/81 | 38 | 5 | 1323 | 7.7 | 120 | 8.5 | 6.0 | 7.2 | - | 12 | - | - | - | - | - | 80°F; Poss XDCR Broke |
| 2E | 6/30/81 | 39 | 5 | 1323 | 7.7 | 120 | 7.3 | 5.0 | 9.2 | - | 13 | - | - | 7.4 | 11.7 | | |
| 3C | 6/30/81 | 40 | 6 | 1500 | 7.7 | 120 | 10.4 | 6.5 | 7.4 | - | 16 | - | - | 7.4 | 12.5 | | |
| 5A | 7/17/81 | 41 | 8 | 1855 | 7.7 | 120 | 15.8 | 9.8 | 9.4 | - | 32 | 19 | 20 | 7.4 | 15.8 | | |
| 6A | 7/17/81 | 42 | 9 | 2032 | 7.7 | 120 | 20.5 | 12.0 | 19.3 | - | 47 | 30 | O.C. | 7.4 | 17.7 | | |
| 11B | 7/17/81 | 43 | 10 | 2209 | 7.7 | 120 | 29.0 | 19.3 | 19.7 | - | O.C. | 32 | O.C. | 7.4 | 18.4 | | |

O.C. = Off Chart

(3) were originally located along a platform diagonal; one in the center, and one each on diagonally opposite corners. In these five drops, motion picture coverage was excluded. Airbag pressure data had generally clean traces, although there were many instances of large magnitude high frequency oscillations that made data interpretation difficult. Platform acceleration data consisted of very large high frequency oscillations at all times, making the data unreadable. In drops 1D and 1F, problems with the Visicorder caused no recording of data. Motion picture photography was added with drop 1E, and was used on drops 1G and 1H in an attempt to see why vibrations were so prevalent. As the films were too dark and of somewhat poor quality, no information was gained. Low pass filters were added to the Visicorder on Drop 1I, rated at 125 Hz, to eliminate the high frequency ringing and vibrating being recorded. These filters helped somewhat, especially with the airbag pressure data, but did little to make the platform acceleration more readable. On drop 1I, a pressure transducer airbag 1 shirt was destroyed due to breaking free from the mounting. One possible reason for noisy data was vibration of the weights against the mountings. A layer of 6 mm plastic foam was installed under each weight in drops 1J and 1K; no reduction in vibrations resulted. On drop 2 an additional accelerometer was cemented to the top of the right end steel weight, and a much cleaner trace resulted, with only small oscillations due to platform vibration. Starting with drop 3, and on all subsequent drops, accelerometers were cemented to the top center of the left, center, and right steel weights. With the data recording problems now solved, one weight was added in each succeeding drop. On these first drops, high speed motion picture photography was done by the Audio-Visual Aids Office using a Hycam 16 mm variable-speed camera with a strobe attachment. The strobe device put a spot on the film edge every 0.01 second, allowing very accurate determination of film speed. Using a motion analyzer, the platform height above the ground was tabulated vs. time. From this, the velocity and acceleration of the platform was calculated, and a peak acceleration value was found; this value is tabulated in Table 3. On drop 4, the undamaged skirt pressure transducer (airbag 7) broke free from its mounting and was destroyed. Even though only two of four pressure transducers remained, testing continued as the more important balloon pressure transducers had survived. Four more drops with more weights added were carried out to see how the platform would stand up to the maximum load, and a mild overload. In drop 11, with 10 weights, skirt 4 ripped, and an accelerometer failed. By mistake, a repeat drop (11A) was carried out before repairing skirt 4; as a result, balloon 4 and skirt 5 experienced damage. At this point testing was suspended. The platform was beginning to break apart, almost half the transducers had failed, and ripped airbags needed repair.

Repairs and refurbishment of the platform included the following:

- a. The top-mounted aluminum angles to which the weights were affixed were removed and straightened.
- b. Balloon 4 and skirts 4 and 5 were removed and repaired. Repairs were done by Mr. Carl Frenning, Matl. Appl. Div., IPL, using neoprene/hypalon coated fabric patches (MIL-C-43285) bonded by room-temperature curing black thiokol adhesive.
- c. Eight 4 x 6 x 200 cm wood stiffeners were inserted between the two plywood facings, bringing the total stiffeners to 18. This added 18 kg, increasing the platform mass from 418 to 436 kg.

d. Side shoes were reinforced with three exterior aluminum channel stiffeners and several interior 90° aluminum angle brackets.

e. Two end shoes were attached.

f. Balloon pressure transducers were relocated, mounted on the underside of the platform rather than on the polyethylene intermediate platform. Skirt pressure transducer mountings were redesigned to hold the transducers positively in place.

g. Splits in the polyethylene intermediate platform were repaired with steel tabs sandwiching the polyethylene, attached with machine screws, and spaced approximately every 15 cm along the split. Three splits were repaired. The polyethylene intermediate platform was fabricated of several sheets butt-welded together; splits occurred on the welds.

The Bertin-supplied threaded fasteners used to mount the airbags consisted of round head machine screws and round slotted nuts. Figure 12 shows both the machine screw head and nut. Both the nut and machine screw head had sharp rough areas; the skirts and sometimes the balloons were abraded and cut by these sharp surfaces. Figure 13 shows typical abrasions on skirt 1. It was at these cuts and abrasions that full scale airbag rips occurred. As the number of test drops increased, cuts and rips were discovered and repaired; Figure 14 shows skirt 4 with several repairs. The aforementioned splits in the polyethylene intermediate platform were repaired as shown in Figure 15. A steel tab is also on the underside of the polyethylene. The nuts were covered with heavy tape to protect the airbag material.

The original test plan was revised in view of the performance over the first 20 test drops. Accelerations were high and the platform seemed overloaded at the design load mass of 2000 kg (9 weights). Rather than risk airbag and platform damage, the mass loading was reduced. Table 4 shows the revised test plan.

Table 4
Revised Test Plan

| Drop No. | No. of Steel Weights | Platform Mass (kg) | Impact Velocity (m/s) | Choke Dia (mm) |
|----------|----------------------|--------------------|-----------------------|----------------|
| 2A | 5 | 1322 | 8 | 120 |
| 3A | 6 | 1500 | 8 | 120 |
| 4A | 7 | 1677 | 8 | 120 |
| 5A | 8 | 1854 | 8 | 120 |
| 7 | 7 | 1677 | 8 | 120 |
| 8 | 7 | 1677 | 7 | 120 |
| 9 | 7 | 1677 | 6 | 120 |
| 13 | 6 | 1500 | 6 | 140 |
| 14 | 6 | 1500 | 7 | 140 |
| 15 | 6 | 1500 | 8 | 140 |
| 16 | 5 | 1322 | 8 | 140 |
| 17 | 4 | 1145 | 8 | 140 |
| 18 | 3 | 968 | 8 | 140 |

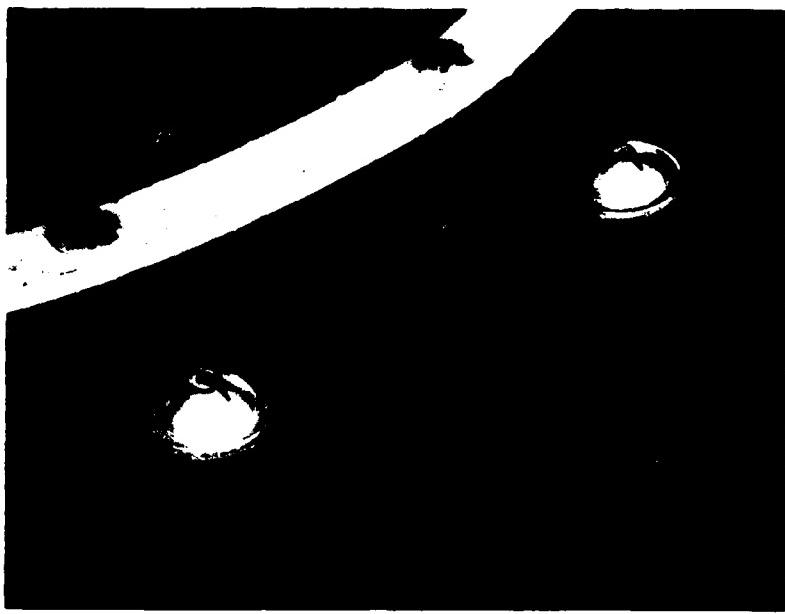


Figure 12. Airbag Mounting Hardware

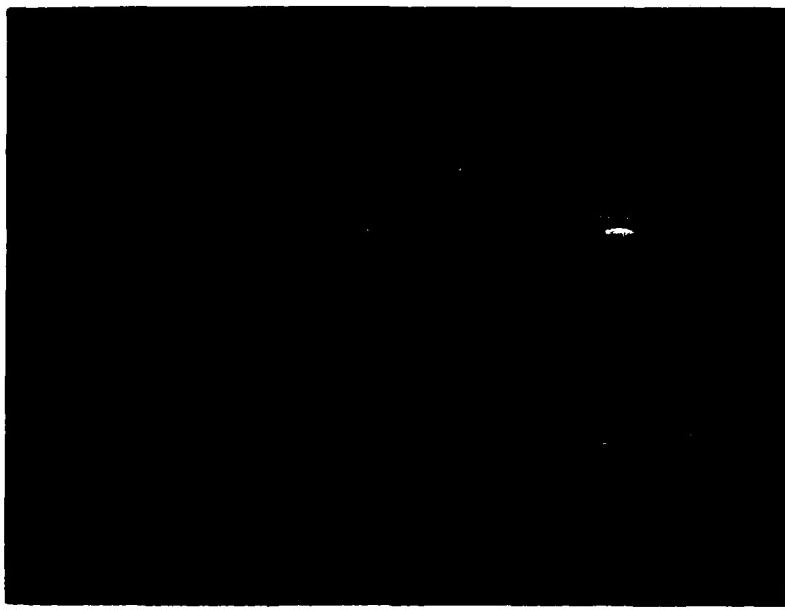


Figure 13. Abrasions on Skirt 1



Figure 14. Skirt 4 with Several Repairs



Figure 15. Repaired Split in Polyethylene Intermediate Platform.

When tests were resumed, the drop height was effectively lowered by 25 cm by attaching the calibrated height cable to the intermediate platform rather than the bottom of the skirt. The theoretical platform velocity at impact was reduced to 7.7 m/s.

Drops 2A through 4A, a total of six drops, were made in ambient temperatures between -4 and 3°C; all other drops were at temperatures above 16°C. Compared to earlier drops, these six drops exhibited higher airbag pressures and lower acceleration readings. The reduced airbag fabric extensibility and flexibility was a probable cause for this behavior.

In drop 2B, skirt 1 was ripped. As the repair patch does make the skirt locally stiffer, and airbag 1 is instrumented for pressure, the skirt was exchanged with undamaged skirt 2 prior to test 7.

Up to drop 7, motion picture films were analyzed on a motion analyzer (Vanguard model M16C) to get position, velocity, and acceleration data. This was time-consuming and results were subject to error due to poor picture quality. On drop 7 and all succeeding drops, a position transducer was used to record position vs. time data. The transducer output was recorded on the visicorder along with pressure and accelerometer data.

On drop 4B a pressure transducer failed. Delivery of additional transducers, previously ordered, was delayed, so a replacement transducer could not be installed.

For drops 13 to 18 the 140 mm chokes were installed. The motion picture camera was moved to get an end view and slowed to the minimum 450 frames/second to make the pictures as bright as possible. The camera was positioned to observe only the airbags during crush. On drop 15 a balloon pressure transducer (7) failed; it was not replaced since no extras were on hand. It was replaced with the skirt pressure transducer prior to drop 2D as the balloon pressure is more useful data than the skirt pressure.

After the series of drops (13 to 18) with the 140 mm chokes installed, the data was reviewed. It was decided to repeat several drops with the 120 mm chokes to get more reliable position data and to confirm previous results. Unfortunately another accelerometer failed, so the sole remaining one was positioned on the center weight. The long-standing order for accelerometers was finally filled prior to test 5A, so the last three tests had 3 accelerometers. Motion picture coverage was not requested on these last 6 repeat drops.

Detailed Drop Analysis

Each platform drop generated a substantial amount of data so it is unreasonable to examine each drop in detail in this report. Three drops were chosen for a detailed analysis: drops 2E, 7, and 6A, representing light, medium, and heavy platform loading, respectively. All three drops had an impact velocity of 7.4 m/s, slightly less than the standard airdrop velocity in the present system. These drops all used a 120 mm choke; the drops made with the 140 mm choke showed essentially the same characteristics but had generally lower peak values of pressure and acceleration. Data charts for these three drops appear in the Appendix as Figures A1 to A13.

Drop 2E, with a total mass of 1323 kg, represents a light load for the 120 mm choke (range 1350-2100 kg). Figure A1 shows the velocity-time data, which was calculated from the position transducer data, and indicates that the platform deceleration took place over about a 0.10 s time interval. The cyclic appearance of the pre-impact data points is due to the position transducer response to a step input when the initial slack in the connecting wire was used up. Slack was necessary since the drop height was 3.25 m and the working length of the position transducer wire was only 2.5 m. The maximum slope of the velocity-time curve is the peak acceleration, 11.7 G. Deceleration from 7.4 to 0 m/s took place over a 0.01 to 0.115 s time interval, giving an average acceleration value of 7.2 G. For all data presented here, time zero was assumed to be the instant the airbag skirts touched the ground.

The ground contact switch near airbag 1 indicated platform contact at 0.177 s; from Figure A1 the platform velocity at this time had just reached zero. This is an indication of complete impact energy absorption; according to the theory of airbag operation, however, zero velocity should occur with the skirts uncrushed. The negative velocity at 0.13 s is due to platform bending at the attachment point of the position transducer, and springing back. The ground contact switch near airbag 7 did not indicate ground contact until 0.28 s, so while the left end of the platform was on the ground, the right end was not; it settled down 0.16 s later. Flexing of the platform during airbag crush was easily seen in high speed motion picture films. Films showed no two-stage crush; the skirts did not gently lower the platform to the ground over a 1 s interval as was expected. Figure A2 shows airbag pressure vs. time for airbags 1 and 7; a damaged pressure transducer is the reason airbag 7 skirt data is missing. The pressure dip at 0.06 s is quite large, in fact airbag 1 skirt completely depressurized for almost 0.2 s. Possible reasons for this behavior will be discussed in the next section of this report. Figure A3 compares the calculated acceleration for airbag 7 with the center accelerometer output. The calculated acceleration is found by using a 0.65 m diameter circular area over which the airbag pressure is exerting an upward force on the platform. The airbag balloon pressure is assumed to be acting against one-eighth and platform mass, so an acceleration value can be calculated. The balloon is tapered, with a top diameter of 0.5 m and a bottom diameter of 0.7 m; the assumed 0.65 m value is the average diameter during the last half of crush when pressure is highest. Quite good agreement is seen between the value of calculated acceleration and the nearby center accelerometer. Good agreement is also seen between peak accelerations in Figure A3 and the 11.7 G value from Figure A1. Figure A4 shows a plot of the individual airbag force vs. the platform distance above the ground for airbags 1 and 7. The pressure dip observed in Figure A2 is also seen very clearly here. The dip occurs with the platform 16 cm off the ground. The area under the curve is the work done by the airbag during crush. The work done can be compared with the kinetic energy of the platform based on one-eighth of the platform mass. It is seen that airbags 1 and 7 together dissipated 8950 N-m, which is 98.8% of the 9056 N-m two-airbag kinetic energy. This data indicates essentially complete impact energy dissipation which agrees well with the zero platform contact velocity shown in Figure A1.

Drop 7 had 354 kg more load mass than drop 2E, giving a moderate total mass of 1677 kg. Figures A5-A8 in the Appendix are drop 7 data. In Figure A5 a peak acceleration of 14.3 G appears, and platform contact takes place at zero velocity. The proper airbag crush sequence, with the skirt slowly crushing only after balloon crush, again did not occur. Average acceleration, over 0.01 to 0.105 s time interval, was 8.0 G. Again, platform bending and

flexing account for some negative (upward) velocity after ground contact. Position transducer data indicated a 5 cm bounce, so some of the upward velocity is due to bouncing. Due to a cloud of dust at impact, motion picture film could not confirm the bounce or suspected platform flexing at impact. Figure A6 shows airbag 1 and 7 pressure peaks to be out of phase, displaced from each other by 0.03 s. The skirt pressures follow the balloons pressures but are considerably lower. Peak balloon pressures for this drop are roughly 50% higher than for drop 2E. The motion pictures showed the platform was level at airbag contact, but the center airbags (2,3,6, and 7) began to exhaust dusty air well before the end airbags (1,4,5, and 8). The act of air exhaustion is documented on Figure A6 by the pressure dip and it is seen airbag 7 experienced the dip before airbag 1. Figure A7 accelerometer data suggests the left end of the platform bounced substantially while the center bounced only slightly. The center accelerometer peak of 14.9 G in Figure A7 agrees well with the 14.3 G peak value from Figure A5. Figure A8 shows that airbag 1 develops a large force much earlier in the crush than airbag 7 and dissipates considerably more energy. If the other left-end airbag (No. 5) developed as much force as did airbag 1, the platform left end probably stopped prior to ground contact and experienced brief airbag-induced bounce. The combined energy dissipation of airbags 1 and 7 was 11190 N-m, which was 97.4% of the 11480 N-m two-airbag kinetic energy. Although unequal airbag performance caused some localized bounce, the nearly complete energy dissipation agrees well with the fact that the platform center contacted the ground at zero velocity.

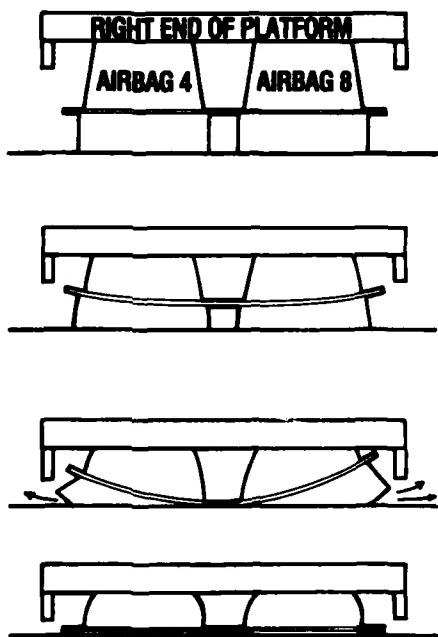
Drop 6A was a heavily-loaded platform drop with total mass of 2032 kg; data for this drop is shown in Figures A9–A13 in the Appendix. Figure A9 shows a peak deceleration of 17.7 G, and ground contact switch data indicates that ground contact occurred at a velocity of 1.0 m/s. The average acceleration over the time interval 0.02 to 0.105 s was 7.9 G. After a flat impact, the platform bounced up 6 cm; the -2 m/s velocity spike just after ground contact is mainly due to platform bending and springing back. Figure A10 shows airbag balloon pressures, ground contact switch activity, and platform position above ground out to 0.53 s. The platform was in contact with the ground for 0.02 to 0.03 s, reached a peak bounce height at 0.25 s, and began contacting the ground again at 0.35 s. On the second impact, the airbags again pressurized with airbag 1 reaching a much higher pressure than airbag 7. Figure A11 shows airbag 1 and 7 pressure curves to have similar shapes, with peak pressures about 60% higher than drop 7. Again the airbag 7 pressure dip precedes the airbag 1 dip, this time by 0.01 s. Airbag 1 skirt pressure dipped below atmospheric pressure at 0.07 s and again at 0.12 s. Possible explanation for this behavior will be discussed in the next section of this report. Figure A12 shows very high accelerometer values, 30 and 50⁺G, due to the shock of ground impact of the platform body at 1.0 m/s. Calculated accelerations peaked at 17.7 and 18.7 G, very close to the 17.7 G value from Figure A9. Figure A13 shows airbags 1 and 7 dissipated 93.5 to 95.5% of the per-airbag kinetic energy, respectively. Going back to Figure A9, the platform velocity at ground contact was 1.0 m/s. Kinetic energy at this velocity is 127 N-m per airbag, or 1.8% of the original value. Thus airbags 1 and 7 dissipated 95.3 and 97.3% of what was assumed to be their share of the platform kinetic energy. Considering the assumptions involved as well as instrumentation inaccuracies, essentially all kinetic energy is accounted for.

In all three drops discussed here, the balloon and skirt pressures built up after the beginning of crush, but then suddenly dipped down and began building up again. This behavior was

unexpected. All three drops also did not exhibit proper crush characteristics; the skirts did not gently lower the platform to the ground after balloon crush. These two events are related, as will be seen in the next section.

Airbag Crush Behavior

In most drops, the pressure dip occurred with the platform 10 to 15 cm above the ground; this can be seen in Figures A4, A8, and A13 for the three drops analyzed in detail. Side-view high speed motion picture films showed only a rush of dusty air (toward the camera) when the platform was about 10 to 15 cm above the ground. End-view film coverage, however (drops 13-18), was much more informative. Figure 16 shows a typical airbag crush sequence based on end-view films.



**Figure 16. Successive Stages
of Airbag Crush, End View**

The inward-facing part of the skirts crush while the outer edges tip upward. This tipping progresses, bending the intermediate platform until it contacts the ground. The outer edge of the skirts then lifts up, exhausting a large amount of air, reducing the skirt pressure to (or below) zero, and greatly lowering balloon pressure. The skirt then flattens and airbag pressure increases again. The pressure-time data shows this behavior as a large pressure dip. The negative skirt pressure occurring just after air exhaustion is probably due to the violent flipping-up action of the skirt causing a mild vacuum.

The flattening of the skirt before the balloon does not follow the theory of operation, as described in the introduction of this report. Reference 5 shows a photographic sequence of an airbag crushing; the balloon crushes completely while the skirt stays uncrushed. Also in a film by Bertin "Utilization of Air Cushioning to Lessen Impact of Parachute Dropped Loads," slow motion footage clearly shows the two-stage crush, with the balloons first crushing over approximately 0.1 s and the skirts crushing for approximately 0.8 s, beginning after balloon crush. The platform velocity is reduced to near zero by the balloon crush.

A letter was sent to Bertin & Cie, France, with a description of the airbag platform, some test results, and a copy of Figure 16. An explanation of the suspected abnormal crush behavior was requested. In reply, Bertin was surprised and puzzled that our results did not agree with theirs. They concluded that the choke area was too small, causing the skirts to be insufficiently fed with air, and to collapse. They suggested the chokes be progressively enlarged until the optimum deceleration is achieved.

Airbag Pressure Variations

All airbag pressure-time data showed the existence of at least two distinct peaks. These peaks varied greatly in size and shape between airbags 1 and 7 on a given drop, and between drops from identical conditions. Figure 17 compares airbag balloon pressure data for drops 2B, 2D, and 4C. These drops were chosen for this figure since they have characteristic shapes: one large peak followed by a much smaller second peak (2B), two approximately equal sized peaks (2D), and a small first peak followed by a much larger second peak (4C). Patterns evident in the data are: (a) most lightly-loaded platforms had a pressure curve similar to that of drop 2B, but a few appeared similar to drop 2D, (b) moderately loaded platforms showed no consistent pattern, having pressure curves with all three shapes, and (c) heavily loaded platforms always had pressure curves similar to the shape of drop 4C. These trends are valid for both 120 mm and 140 mm choke sizes. Lightly loaded drops included light load masses impacting at 7.4 m/s, and heavier load masses impacting at lower velocities. Two more trends evident in the data and observable in Figure 17 are that airbag 7 pressures were almost always lower than those of airbag 1, and in the majority of cases the airbag 1 and 7 pressure curves were of similar shapes for a given drop. A notable exception to the latter is drop 7, seen in Figure A6. It should also be noted that drops 2B and 2D did differ in the ambient temperature, 25°F for 2B but 80°F for 2D. The stiffer airbag coated fabric at the lower temperatures may have contributed to the differently-shaped pressure curves.

Platform Acceleration

One of the major goals of this test program was to determine the sensitivity of the platform impact acceleration to variations in load mass, impact velocity, and choke size. Average and peak platform accelerations for the final fourteen drops are tabulated in Table 5.

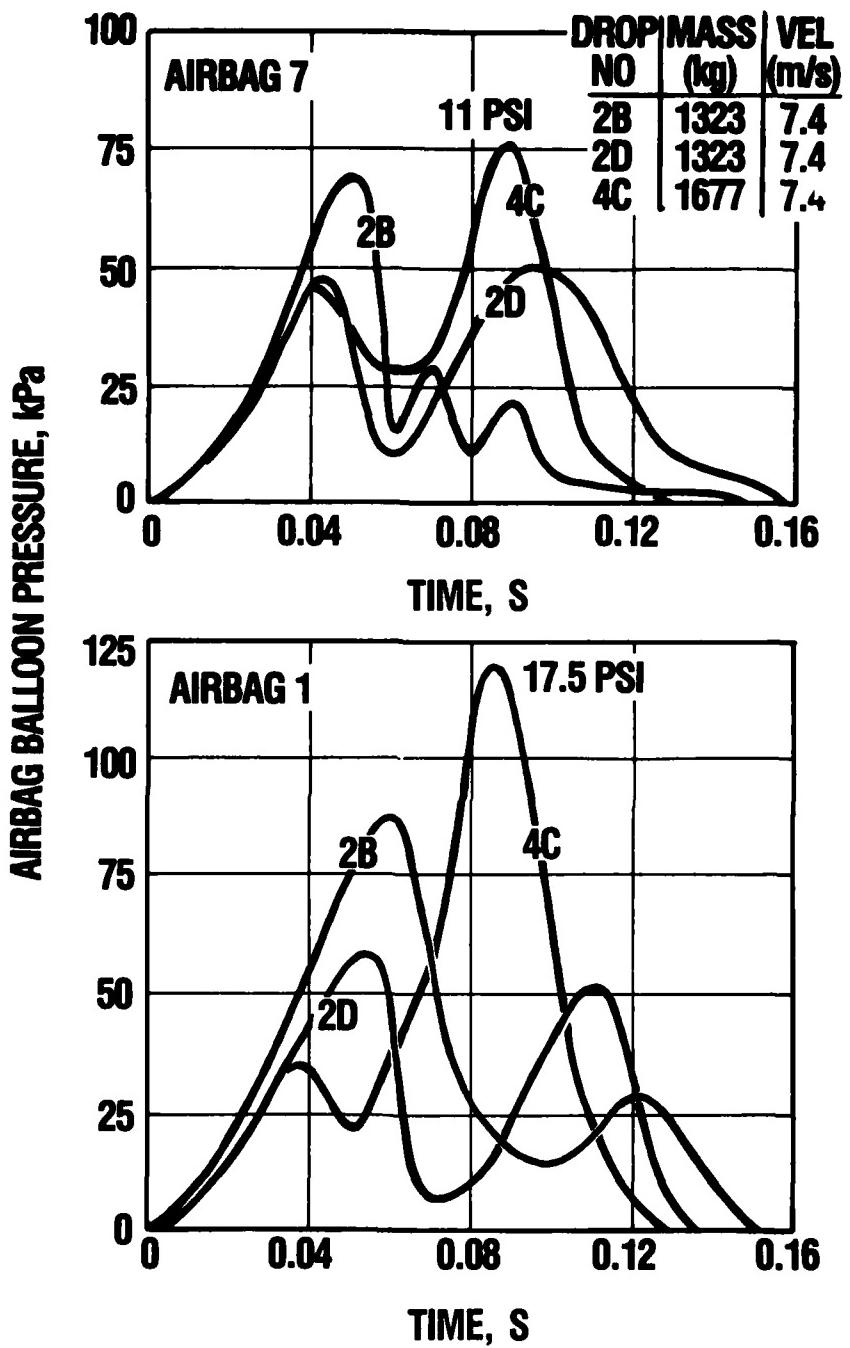


Figure 17. Airbag Balloon Pressure Comparison: Drops 2B, 2D, 4C

Table 5
Acceleration Data, Selected Drops

| Drop No. | Total Mass (kg) | Impact Velocity (m/s) | Average Acceleration | | | Peak Acceleration | | |
|----------|-----------------|-----------------------|-------------------------|------------------|--------------------------|------------------------|------------------------|--------------------------|
| | | | $\Delta v/\Delta t$ (G) | L & C Accmtr (G) | Calculated Bag 1 & 7 (G) | Vel-Time Max Slope (G) | C. Accmtr Smoothed (G) | Calculated Bag 1 & 7 (G) |
| 2E | 1323 | 7.4 | 7.2 | 6.6 | 6.3 | 11.7 | 13 | 11.7 |
| 3C | 1500 | 7.4 | 7.8 | 7.4 | 6.5 | 12.5 | 16 | 10.5 |
| 7 | 1677 | 7.4 | 8.0 | 7.2 | 5.3 | 14.3 | 15 | 13.7 |
| 5A | 1855 | 7.4 | 7.9 | 8.0 | 5.8 | 15.8 | 19 | 12.6 |
| 6A | 2032 | 7.4 | 7.9 | 9.4 | 5.9 | 17.7 | 30 | 18.2 |
| 11B | 2209 | 7.4 | 8.7 | 9.6 | 7.2 | 18.4 | 32 | 20.6 |
| 8 | 1677 | 6.4 | 4.9 | 5.2 | 5.0 | 10.2 | 10 | 11.0 |
| 9 | 1677 | 5.4 | 3.6 | 3.7 | 3.7 | 6.8 | 9 | 7.4 |
| 18 | 968 | 7.4 | 6.3 | 7.0 | 6.1 | 8.8 | 14 | 10.6 |
| 17 | 1145 | 7.4 | 5.9 | 6.1 | 6.0 | 9.0 | 13 | 12.4 |
| 16 | 1323 | 7.4 | 7.1 | 7.3 | 6.8 | 11.6 | 24 | 12.6 |
| 15 | 1500 | 7.4 | 7.0 | 8.0 | 5.9 | 13.6 | 18 | 11.6 |
| 14 | 1500 | 6.4 | 5.2 | 6.5 | 4.5 | 10.2 | 13 | 8.6 |
| 13 | 1500 | 5.4 | 3.6 | 4.9 | 4.2 | 7.3 | 10 | 7.4 |

Plotted in
Figures 18-20

Three average accelerations are given: the first is the change in velocity divided by the crush time, or $\Delta v/\Delta t$, taken from the velocity-time curve for each drop, the second is the mean value of the left and center average accelerations (determined from accelerometer data by using a planimeter), and the third was found by determining average accelerations (again using a planimeter) of the airbag 1 and 7 calculated acceleration curves, and averaging the two values.

Three peak accelerations are given: the first is the steepest portion of the velocity-time curve, the second is the peak of the smoothed center accelerometer output, and the third is the mean peak value of the airbag 1 and 7 calculated accelerations.

It is felt that the best indication of platform average acceleration is the $\Delta v/\Delta t$ data. It agreed quite well with calculated peak acceleration data, but was considered more accurate because the calculated data was based on pressure data from only two (of eight) airbags, and assumptions were made regarding the area the airbag pressure acted upon. There were substantial differences between the $\Delta v/\Delta t$ data and the center accelerometer average acceleration data. The center accelerometer was subject to platform vibrations, local platform bending, and often recorded spikes due to ground contact. The contact spikes, worst with the heavier loads, occurred approximately at peak airbag pressure. This fact, coupled with often uneven ground contact due to local platform bending, made it impossible to distinguish between airbag-related

and contact-related center accelerometer output. Also, ground contact shocks were more severe with the asphalt surface used in these tests than they would be with typical grass or earth drop zones. To study airbag performance up to the point of ground contact as we are doing, the $\Delta v/\Delta t$ data, free of extraneous accelerations due to vibration and ground contact, provides the best evaluation.

For peak accelerations, the velocity-time maximum slope value is most representative, for the same reasons. Figure 18 is a plot of these Table 5 peak and average acceleration values against total mass, for impact velocity constant at 7.4 m/s.

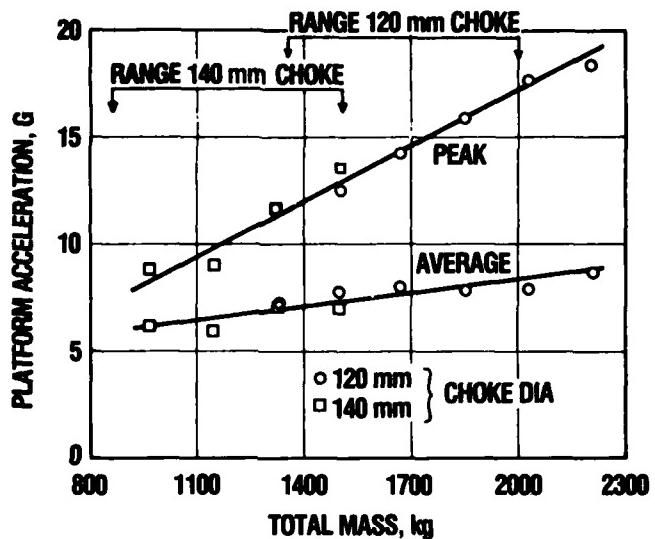


Figure 18. Platform Peak and Average Accelerations at Impact Velocity of 7.4 m/s, Variation with Total Mass

Over the mass range for each choke, peak acceleration increases by about 50% while average acceleration increases only about 20%.

Figure 19 shows Table 5 average and peak accelerations as a function of impact velocity, with platform total mass held constant. As impact velocity increases, both average and peak platform acceleration increases. For the two different load masses, the assigned choke diameters provided very similar peak and average platform accelerations over the range of impact velocity.

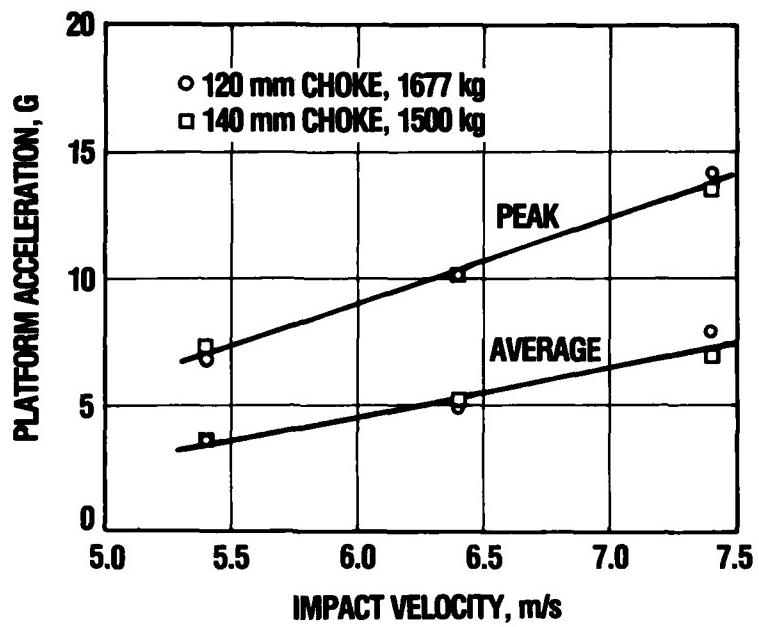


Figure 19. Variation of Peak and Average Acceleration with Impact Velocity

Figure 20 is a repeat of Figure 10, which showed predicted acceleration data (shaded) provided by Bertin in the airbag instruction manual (Reference 6). Average and peak acceleration data points from Table 5 are shown for comparison to the predicted range. The "theoretical" curve was found by assuming a constant acceleration over the 0.4 m balloon crush distance, equating kinetic energy and balloon work, and solving for acceleration. For a given impact velocity, the theoretical acceleration represents the minimum constant acceleration required to totally stop the platform over the 0.4 m balloon crush distance. In Reference 5, Bertin stated that the predicted peak acceleration of the platform is about 50% higher than the theoretical value due to the non-rectangular nature of the airbag force-distance curve. This is shown on Figure 20 by the $\gamma = 1.5 V^2/2h$ curve. The peak acceleration test data is generally well above this curve. A third curve was drawn, $\gamma = 2V^2/2h$, in which peak accelerations are 100% higher than the theoretical curve; peak acceleration test data fits this curve quite well.

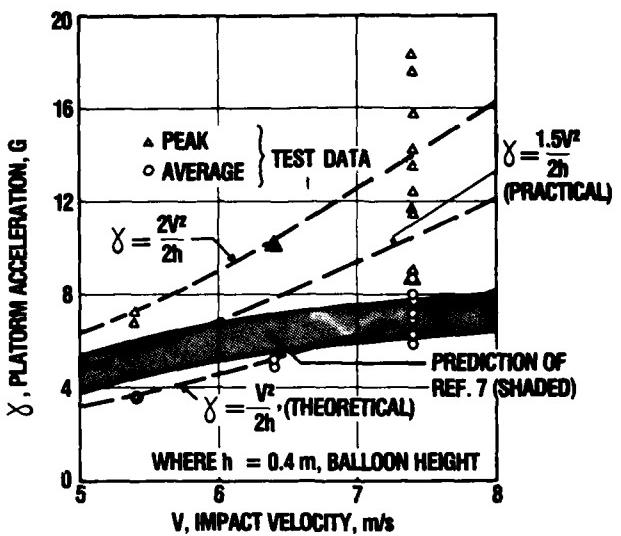


Figure 20. Platform Acceleration vs.
Impact Velocity; Comparison of Test Data,
Ref. 5 Theoretical and Practical
Curves, and Ref. 6 Predicted Range

The shaded area is the Bertin-predicted "calculated acceleration at the center of gravity of the load." The average acceleration test data was, in most cases, within or below this shaded area; only the heavily loaded platforms at 7.4 m/s impact velocity exceeded Bertin's predictions. The theoretical curve approximates the average acceleration data extremely well. Due to the premature skirt collapse, the airbag did not stop the vertical motion over just the balloon crush distance; the crushing stroke was the entire airbag height less the height of the side shoe, or 0.6 m. Thus the balloon height of 0.4 m used in the theoretical acceleration calculation was only 66% of the actual crushing distance. Since only about 60% of the airbag stroke is effective, the theoretical acceleration curve is based on the effective stroke, and should agree well with the test data.

CONCLUSIONS

The balloon-skirt airbag design is very different from the barrel-shaped and cylindrical airbags covered in the Literature section. Even with an open bottom and no burst diaphragm, the balloon-skirt airbag had a more effective stroke and a quicker pressure rise. The balloon-skirt airbag has also been well documented by Bertin motion picture films and reports to exhibit no buckling due to horizontal velocity at impact. Therefore two major drawbacks of airbags, small effective stroke and buckling, are minimized and eliminated, respectively, by the balloon skirt design.

The airbags did not perform physically as predicted, however. The skirt tended to flip up and exhaust air rather than remain filled for the approximate one second as observed in the Bertin film. In correspondence with Bertin, the cause of the skirt premature collapse was concluded to be a too small choke area. It is believed that this behavior, if not corrected,

would adversely effect the platform ground slide feature. This behavior did not seem to increase the average acceleration of the platform, but probably caused higher than predicted peak accelerations.

Average accelerations of the platform were close to the predicted values by Bertin, but even closer to the theoretical average based on 0.4 m balloon crush.

In the present airdrop system, descent velocity is intentionally kept as constant as possible at about 8 m/s. Variations around this value will generally be small, probably less than ± 1 m/s. The variation of platform acceleration with total mass rather than impact velocity is therefore more important. It was found that average accelerations were quite insensitive to variations in total mass. From the low to the high end of the mass range for each choke, with impact velocity held constant, average accelerations increased only about 12%. Peak accelerations increased approximately 50%.

With total mass held constant, variation of platform acceleration with impact velocity was more pronounced. As impact velocity increased from 5.4 to 7.4 m/s for both chokes, the peak and average accelerations increased by about 100%.

The peak acceleration value, over the range of total mass and impact velocity test data, was approximately 100% greater than the average acceleration value. Bertin predicted the excess of peak over average acceleration to be only 50%.

There are some possible problems in practical use of these airbags. The skirts at times acquired a fold that had to be pulled out before a drop. Cold weather stiffness of the airbag coated fabric could affect deployment. Also, if the bags were wet and froze in the folded position, deployment could be affected. The airbag fabric did occasionally rip, but only where weakened by abrasion with sharp-edged metal fasteners. Improved fastener design could eliminate this problem.

The 2000 kg total mass limitation of these airbags would permit use with only the lightest of airdropped equipment. Bertin has also designed a scaled-up version of this airbag that has a capacity four times as great. Eight of these larger airbags would handle an 8000 kg mass (17,600 lb weight).

The balloon-skirt airbags, although exhibiting premature skirt crush, did prove to be durable, reusable and basically effective over an adequate range of total mass and impact velocity. If the abnormal skirt crush can be corrected, the balloon-skirt airbags have great potential for use as airdrop impact shock absorbers.

REFERENCES

1. Madaffer, M.C. Evaluation of Three Types of Airbag Decelerators by Drop Tests, Technical Note WCLE-54-11, Wright-Patterson AFB, Ohio, December 1953 (AD 857025).
2. Turnbow, J. and W. Ogletree. The Energy Dissipating Characteristics of Airbags, US Army QMR&E Command Contract DA 19-129-QM-1383 to University of Texas Structural Mechanics Research Laboratory, Austin, Texas, August 1959 (AD 228 787).
3. Tomcsak, S. Decelerator Bag Study, Technical Report WADC-TR-59-775, Wright-Patterson AFB Contract AF 33(600)-30825 to Goodyear Tire and Rubber Co., Akron, Ohio, June 1960 (AD 243 159).
4. Browning, A.C. A Theoretical Approach to Airbag Shock Absorber Design, Technical Note ME369, Royal Aircraft Establishment, Farnborough, England, February 1963 (AD 421 946).
5. Lebargy, P. Damping of Parachute Loads, Final Report, Technical Memorandum 68IF29, Bertin & Co., Plaisir, France, November 1968.
6. Croix-Marie, F. and P. Lebargy. Airdrop Landing Platform Damper No. 1, Document 79-58, Bertin & Co., Plaisir, France, November 1979.

APPENDIX

TEST DATA

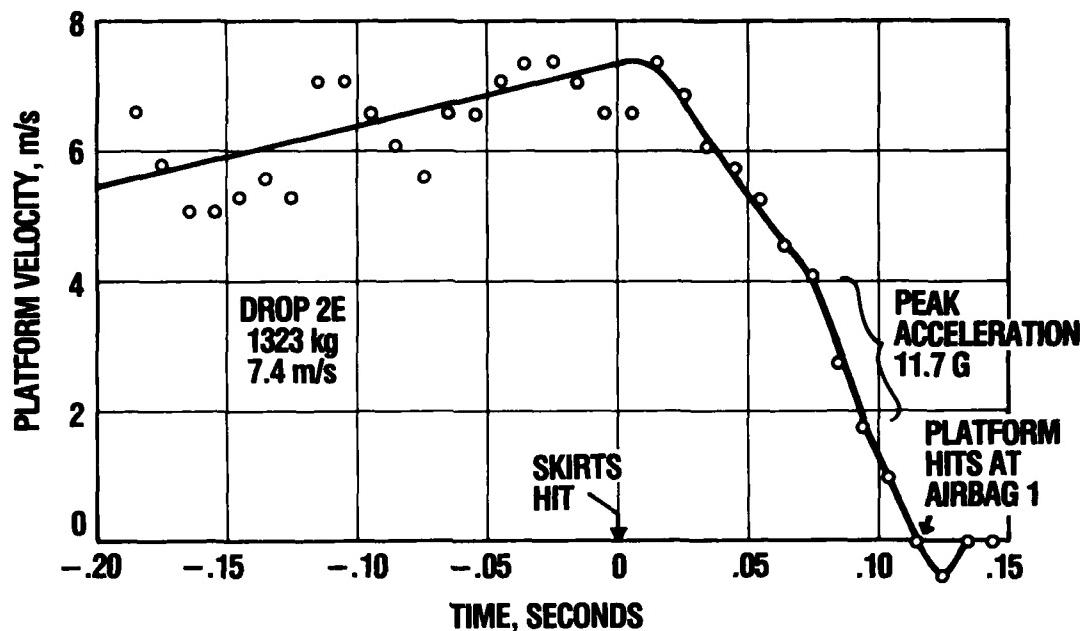


Figure A1. Velocity vs. Time, Drop 2E

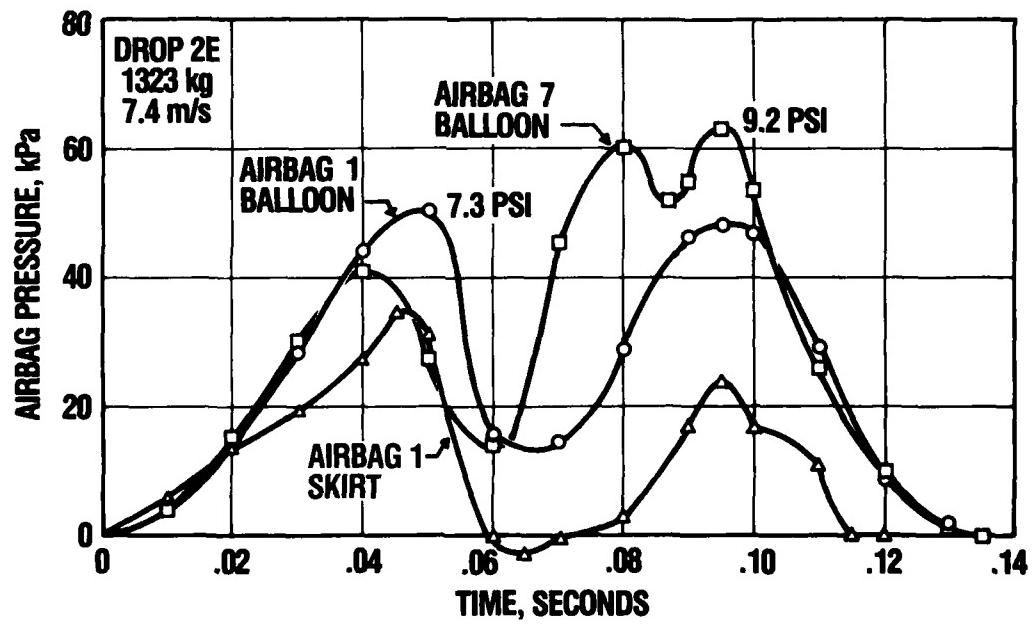


Figure A2. Airbag Pressure vs. Time, Drop 2E

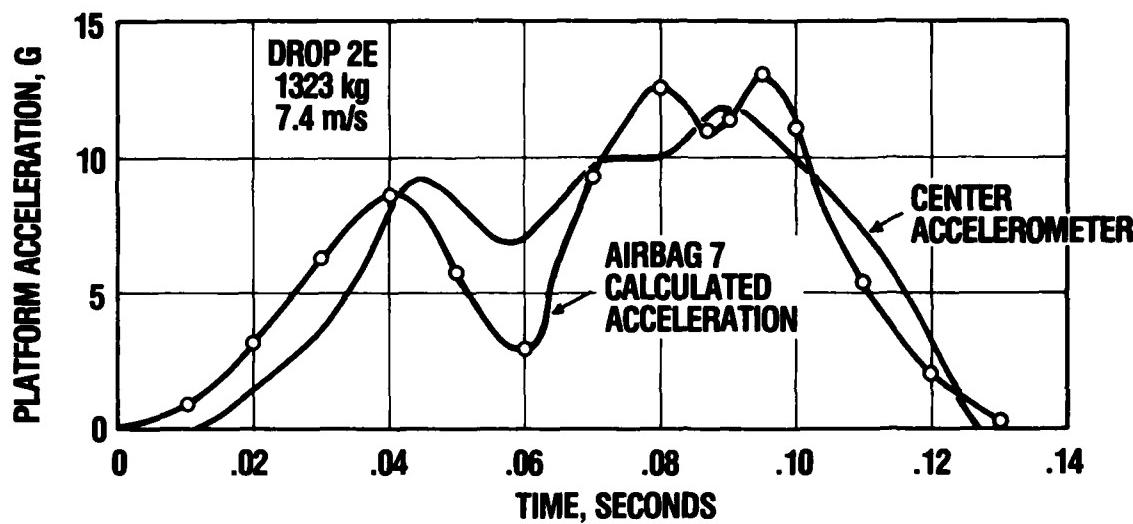


Figure A3. Platform Acceleration vs. Time, Drop 2E

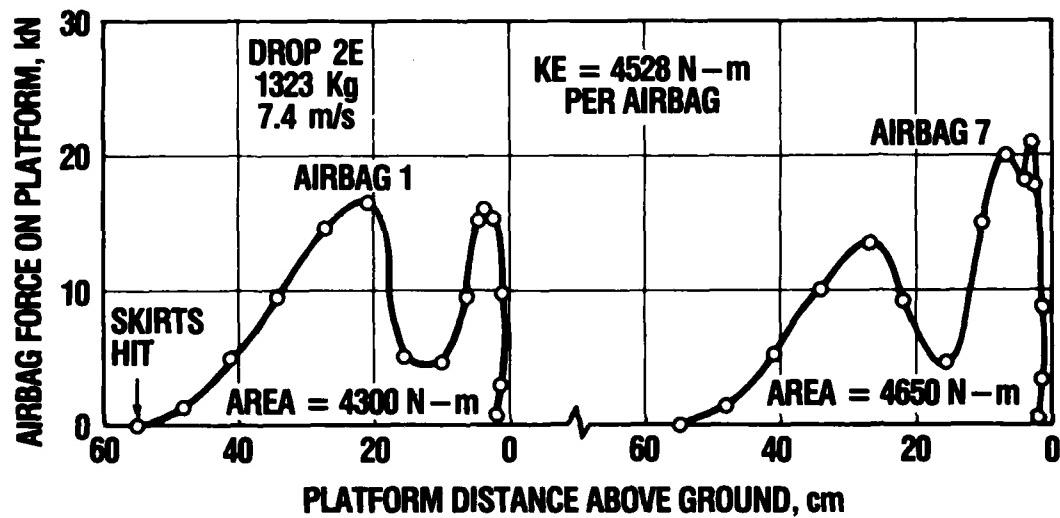


Figure A4. Airbag Force vs. Distance, Drop 2E

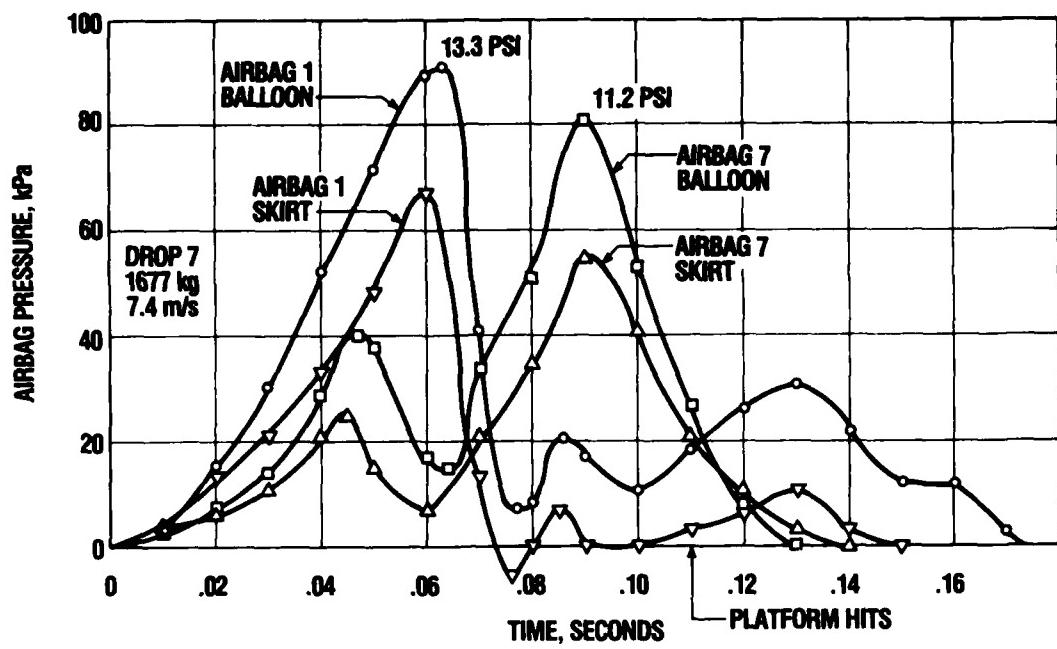


Figure A6. Airbag Pressure vs. Time, Drop 7

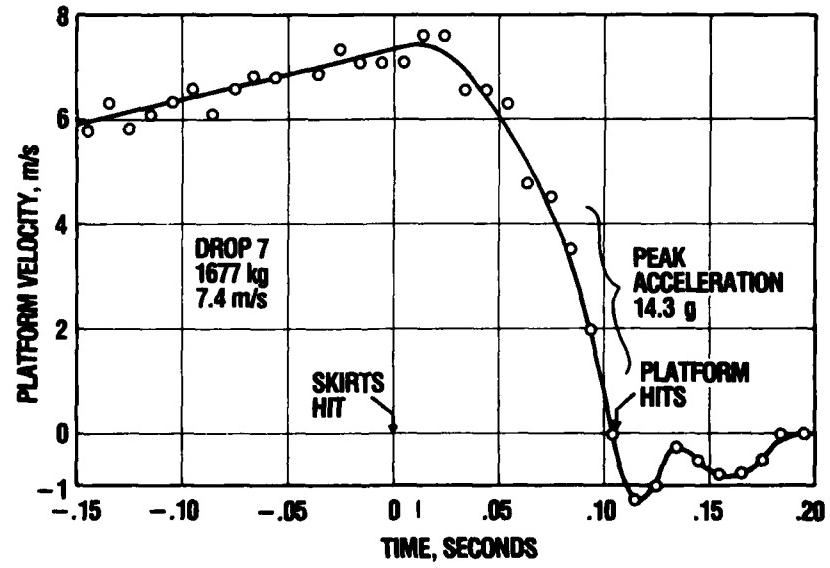


Figure A5. Velocity vs. Time, Drop 7

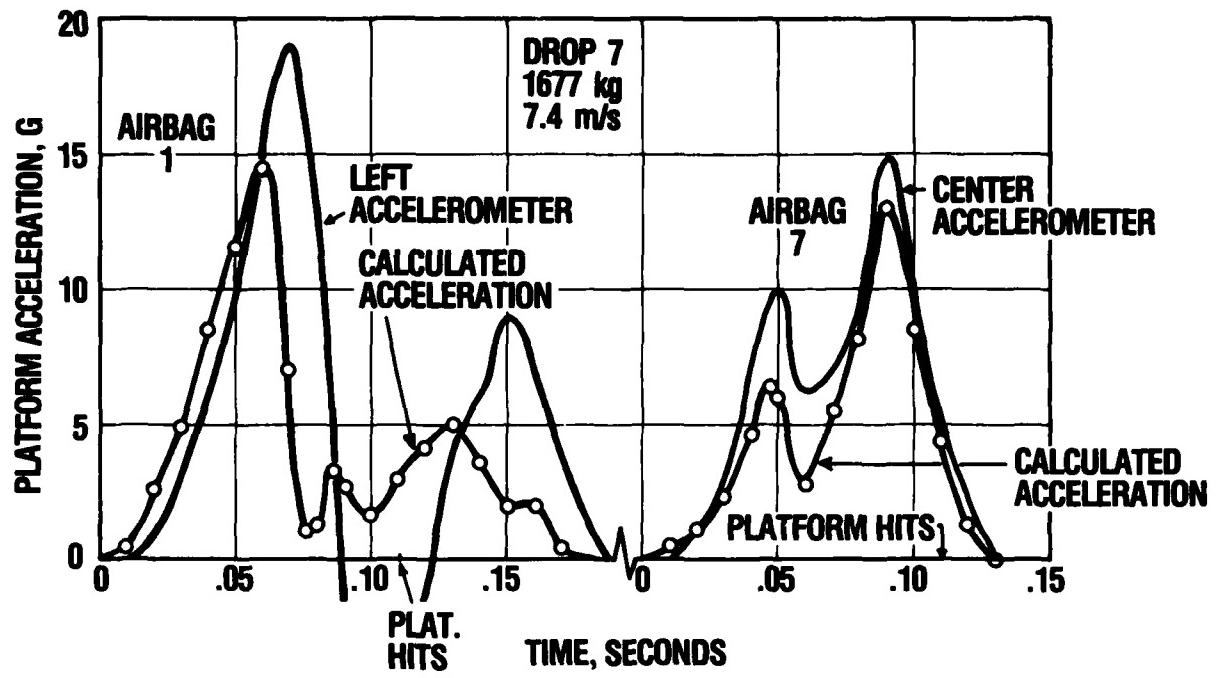


Figure A7. Platform Acceleration vs. Time, Drop 7

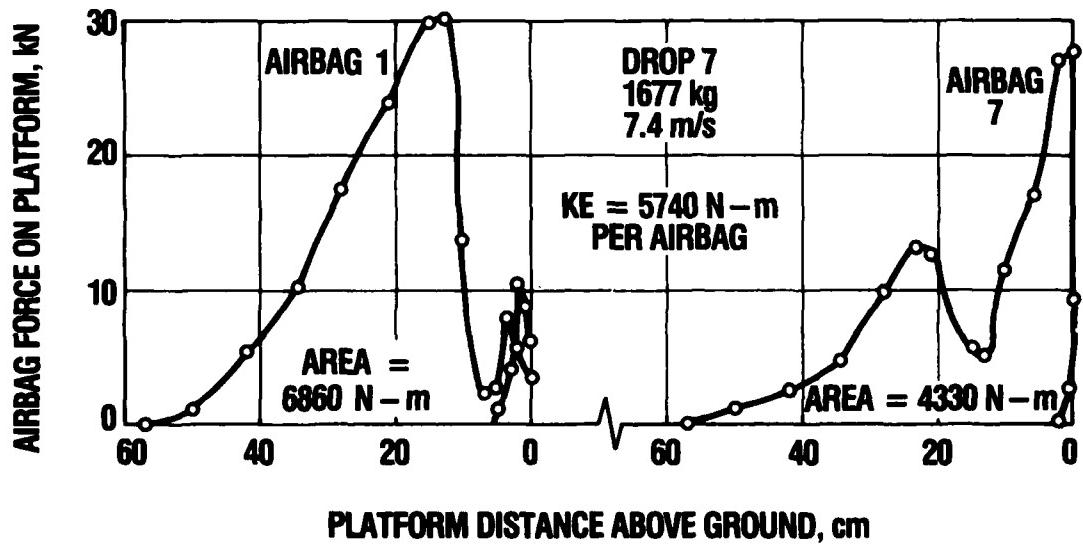


Figure A8. Airbag Force vs. Distance, Drop 7

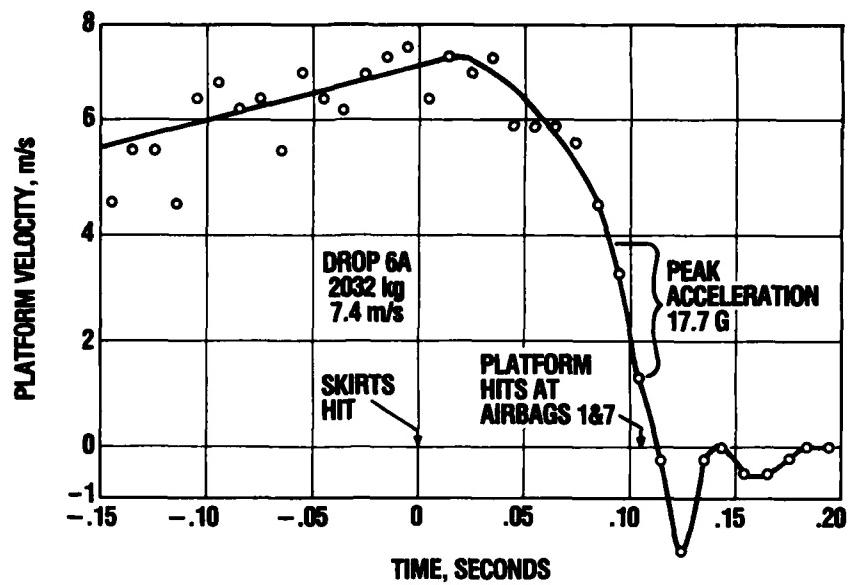


Figure A9. Velocity vs. Time, Drop 6A

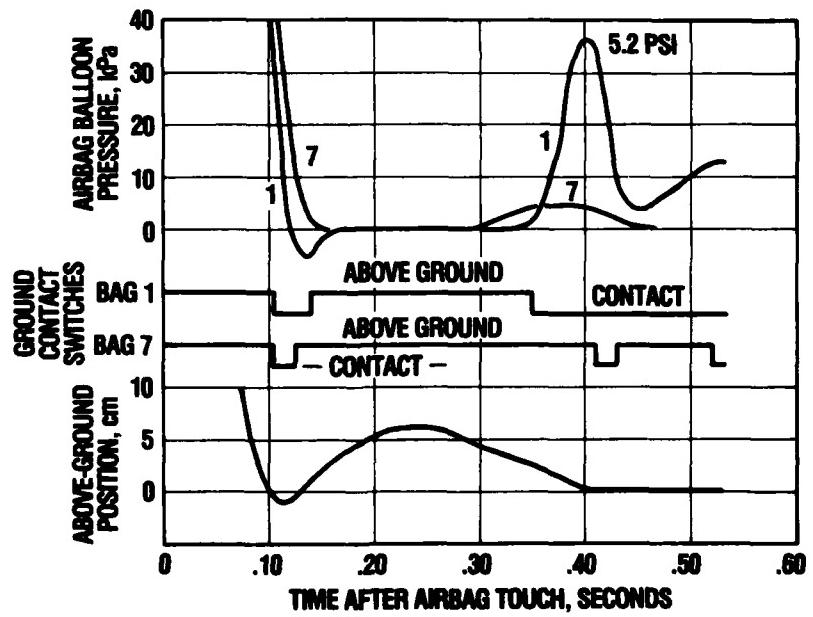


Figure A10. Platform Dynamics After Impact, Drop 6A

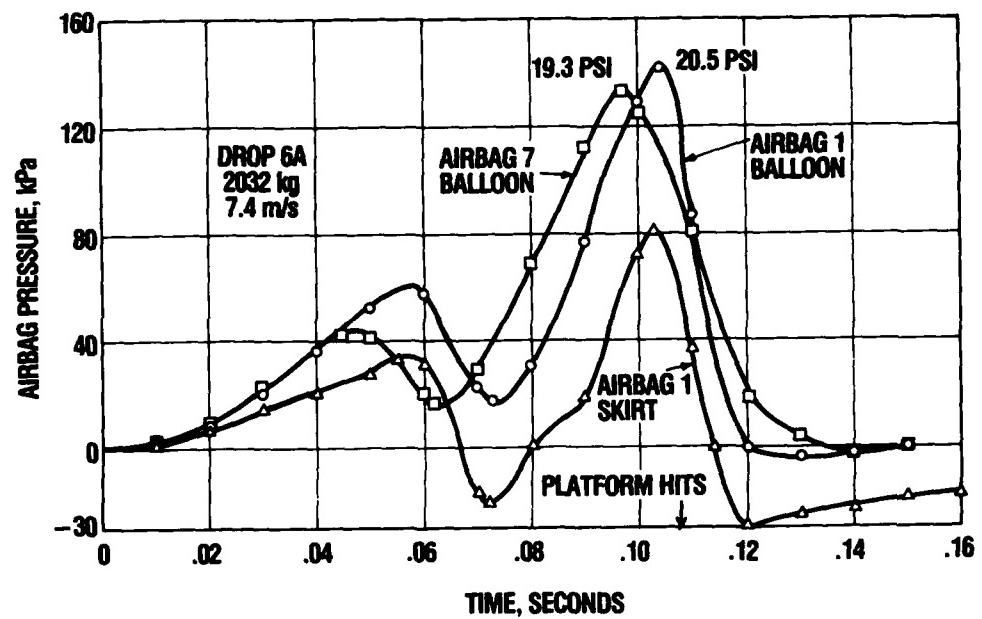


Figure A11. Airbag Pressure vs. Time, Drop 6A

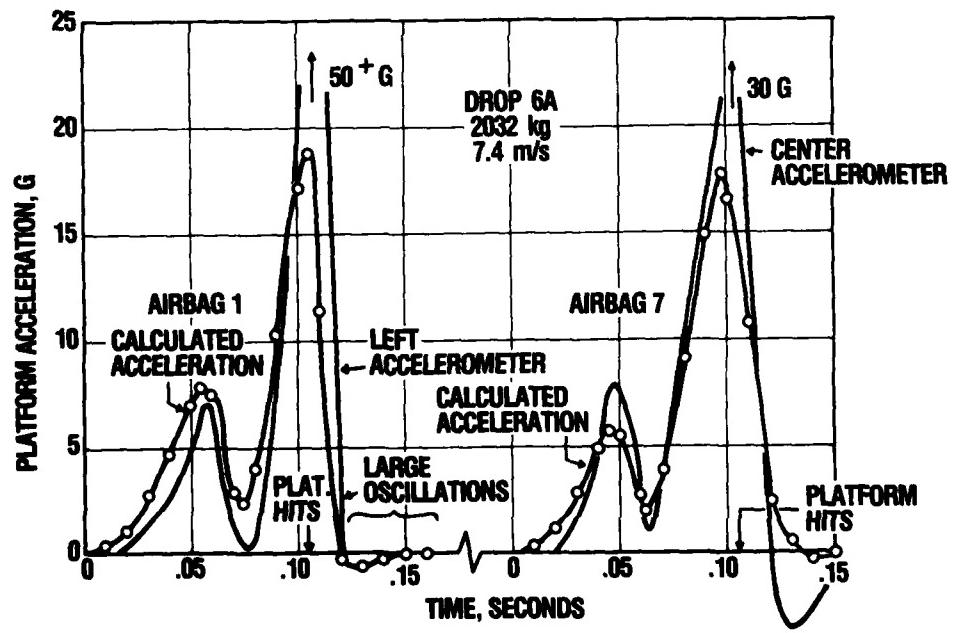


Figure A12. Platform Acceleration vs. Time, Drop 6A

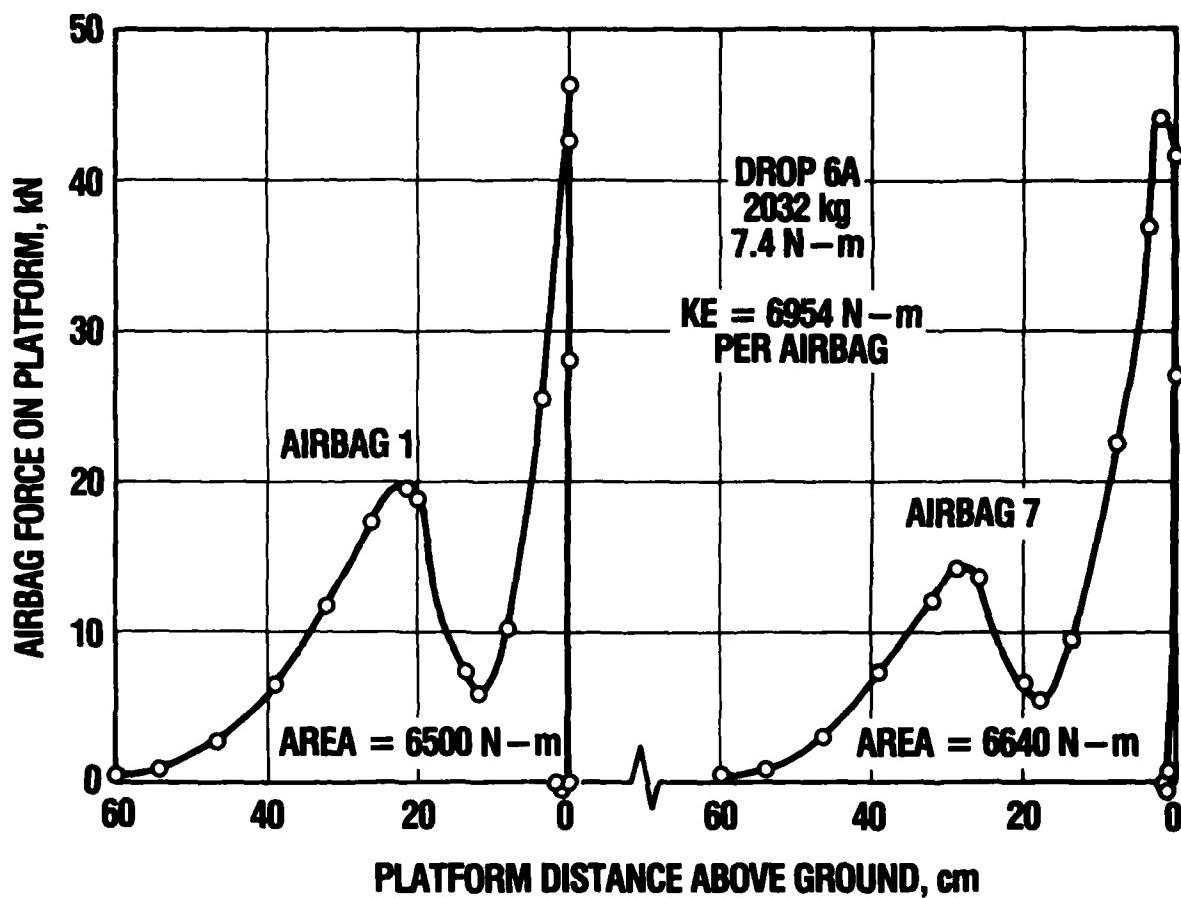


Figure A13. Airbag Force vs. Distance, Drop 6A